

SANDS AND CRUSHED ROCKS

FORD TECHNICAL PUBLICATIONS

SANDS AND CRUSHED ROCKS

VOLUME II
THEIR USES IN INDUSTRY

BY

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'KILNS AND KILN BUILDING,' ETC.



LONDON
HENRY FROWDE AND HODDER & STOUGHTON
THE LANCET BUILDING
1, BEDFORD STREET, STRAND, W.C.2

First printed 1523.

Printed in Great Britain by R. & R. CLARK, LIMITED, Edinburgh.

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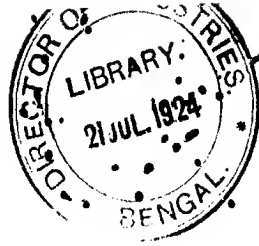
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CHAPTER I

THE USES OF SANDS IN BRICK-MAKING

In the various branches of the brick-making industry, sands play a small yet important part, and in many cases they are irreplaceable by any other material. For this industry, sand is used chiefly in the manufacture of (a) clay bricks, (b) lime-sand bricks, (c) artificial stone, (d) light-weight bricks, and (e) refractory bricks.

CLAY BRICKS

The extent to which sands are used in the manufacture of clay bricks varies considerably in different parts of the country; they serve many useful purposes, the chief of which are :

1. Sand assists in preventing undue contraction of the clay.
2. The salts in the sand are, in some cases, useful, as they decompose on burning, and assist in fluxing the clay. More often such salts are objectionable, as they cause "scum."
3. Sand prevents the bricks from sticking to the mould in which they are made.
4. Sand assists in giving a pleasing "face" to the bricks.
5. Sand prevents the bricks from sticking together during drying and burning.
6. Sand modifies the hardness and texture of the bricks.
7. Sand is used as a constituent of glazes for bricks.

The use of sand in preventing the undue contraction of the clay is one of the most important purposes for which it is employed. In many places, particularly in the south of England, the materials worked for brick-making consist of deposits of highly plastic clay, which in its natural state can only be used with great difficulty, as the bricks crack badly during the drying and burning, so that some non-plastic material must be added to lessen the shrinkage. The cracking is due to the colloidal material in the clay not being distributed over a sufficiently large surface, and this serious defect may, therefore, be prevented by the addition of a non-colloidal solid material to the clay. Almost any non-plastic material which will withstand the heat to which the bricks are exposed in burning

and which does not affect the bricks in any way, may be made to reduce the shrinkage, and brick-dust or "grog" is sometimes used for this purpose. Sand is usually the cheapest, and as it is generally quite satisfactory, it is largely employed. When a natural mixture of sand and clay in suitable proportions can be obtained, it is preferable to an artificial mixture of sand and clay. Thus, in Suffolk, white bricks have been made since the days of Queen Elizabeth from glacial deposits which are either chalky boulder clays or glacial brick earths, which have probably resulted from the washing of the glacial clays. Such deposits are often true loams (I. 125) and contain as much as 30 per cent of sand, so that they may be used just as they are with perfectly satisfactory results. Loams in other districts produce red, yellow, and buff bricks respectively. Such loams are largely used for brick-making; their value is dependent on the fact that they contain a large proportion of sand which neutralises the excessive shrinkage of the plastic clay of which they are also composed. Some loams, however, contain an excessive proportion of sand and are loose and incoherent, so that they do not make satisfactory bricks without the addition of some other material, such as chalk, to bond the particles more securely together.

When suitable natural mixtures of sand and clay are not available, a proportion of sand (the amount being ascertained by trial) is mixed with the clay before it is made into bricks. Such a mixture produces sound bricks of good quality and accurate shape.

As the sand is much coarser in texture than the clay and consists of much larger particles, the bricks are more porous than if the clay were used alone, just as sand added to a clayey soil produces a lighter soil (see Chapter VIII.), which is more permeable to air, gases, and water. In most cases this increased porosity is useful rather than harmful, but it could generally be avoided by finishing the burning at a higher temperature and thereby producing sufficient fused material to fill the pores. Care is needed to prevent the bricks from warping as a result of overheating.

Chemical Composition of Sand.—The composition of sands used in brick-making must be carefully considered, or serious difficulties may occur. The sand should be sufficiently pure, so as not to fuse during the burning of the bricks; as a comparatively low temperature is used in burning most building bricks, this requirement is not serious. Where the bricks are burned at a very high temperature, the presence of metallic oxides, alkalies, etc., in the sand is undesirable; this applies more particularly to the use of sands in making refractory bricks (Chapter VII.).

From a chemical point of view the general composition of the sand is less important than the presence or absence of soluble salts. For red bricks, it is important that sands containing an appreciable proportion of soluble salts should not be present, or a white scum or "sweat" (I. 193) will form and discolour the bricks. Thus, sea sands, which are very liable to contain such salts, should not be used for mixing with brick clay.

SANDS FOR CLAY BRICKS

Felspathic and micaceous sands may be used where the temperature of burning is not high enough to cause too much fusion. Felspathic sands are preferable to micaceous ones as they are less readily fused, the grains being more compact than the thin flakes of mica. Calcareous sands may be used if the lime is in an insensibly fine form, but if the grains are large they may cause "blowing" and the destruction of the brick made with them.

If a sand contains carbonaceous matter, soluble salts, or other undesirable impurities, it may sometimes be purified by washing (F. 384), though the cost is usually prohibitive. Many micaceous sands may be cheaply improved by washing, as the light flakes are readily separated in a stream of running water.

The chemical composition of the sand is important in the manufacture of the white bricks made in Devonshire, Dorsetshire, Cambridgeshire, Norfolk, and Essex. Sands used for such bricks must be very low in iron, as this constituent would spoil the white colour of the bricks if present in sufficiently large quantities, since iron compounds (chiefly in the form of yellow or brown films or coatings of the sand grains) turn red when the bricks are burned. Pure sands must, therefore, be used in making white bricks, the most suitable being the same as those used for glass-making; as these occur in various parts of the counties named, there is usually little difficulty in obtaining a suitable sand. The principal sands occurring in the areas making white bricks are those of Ashurstwood (I. 121), Fairlight (I. 121), and Bulverhythe (I. 122), in Sussex; Aylesbury (I. 119), in Buckinghamshire; Aylesford (I. 119) and Bearsted (I. 119), in Kent; Godstone (I. 119), Oxted (I. 119), and Reigate (I. 119), in Surrey; Leighton Buzzard (I. 119), in Bedfordshire, and King's Lynn (I. 120), in Norfolk. Many of the other sands in these counties are unsuitable, as the iron compounds in them make them turn red when heated.

Unless the sand is naturally dry, it must be dried artificially.

The *physical nature* of the sands used for mixing with clay for brick-making is also important. The *grain-size* should generally be between 30- and 120-mesh. Where too coarse a sand is used, the arrises of the bricks are not sharp, as unduly large grains project from the brick. A sand composed of medium-sized grains is generally the most satisfactory.

The *shape of the grains* of sand should be such as to make them sharp and angular, in order that the grains may interlock to some extent. Rounded grains roll over each other and so do not produce such strong bricks.

In most cases, sands suitable for brick-making occur either in association with, or very near to the clays requiring such additions, so that little trouble is experienced in securing a suitable grade of sand.

One of the most notable exceptions to this statement occurs over a large area of London clay, which is quite unsuitable for use alone, and yet forms so extensive a deposit that only on its borders can

sand be found in association with it. Nearer the centre of the deposit no suitable sand occurs, and consequently any sand needed in that area is usually taken from the bed of the Thames near Woolwich, though other sands are also used to some extent. In other areas, where no suitable sands occur in the same geological strata as the clays, sands from the overlying or adjacent deposits of glacial drift may often be employed, though care should be taken that they do not contain a notable proportion of calcium carbonate, which is liable to crack the bricks after they have been taken out of the kiln.

The *proportion of sand* to be added to any clay must usually be found by trial. It is seldom worth while to add less than 5 parts of sand to 100 parts of clay, and in some cases equal parts of sand and clay have given the best results. It is by no means unusual to have 4-8 cwt. of sand in the mixture used to make 1000 bricks.

Unsuitable sands must not be mixed with the clay used for making bricks, especially those mixtures of exceedingly fine sand and clay known as *silts* (I. 159). These silts may sometimes be used alone, provided the necessary care and skill are used; thus, the silt of the river Humber has been used for many of the bricks in Grimsby. Other silts have also been used for making building bricks, but they cannot be recommended for this purpose.

Sands containing soluble salts are very undesirable in brick-making, as they are liable to cause scumming (I. 193), but if the bricks can be burned at a sufficiently high temperature, the salts may combine with the clay and thus form a slightly and scarcely visible glaze on the bricks. Insoluble salts in a sand are often an advantage, as they combine with the clay during the firing and act as a flux, thus increasing the strength of the bricks as well as helping to produce a pleasing colour.

Limestone dust, crushed lime or chalk are not usually suitable substitutes for sand, nor should a calcareous sand be mixed with clay to be used for bricks. Chalk is much less harmful than limestone, and if thoroughly mixed with the clay (it is necessary first to produce a slurry or suspension of clay in water, as ordinary mixing in a pug-mill is not sufficient), it is sometimes used to act as a flux and increases the strength of the bricks. Coarse chalk and limestone tend to damage the bricks by "blowing."

Artificial sands used to reduce the plasticity and shrinkage of clays include "grog" or ground bricks, crushed rocks of various kinds, ashes, and "soil."

Grog has the advantage of having the same composition and properties as the finished bricks, and it does not expand and cause "slipping" or cracks, as occasionally happens when sand or crushed rock is used.

Ground rock, if sufficiently siliceous, may usually be substituted for sand, though the cost of grinding generally makes its employment prohibitive.

Ashes are sometimes ground to powder and used as a substitute

for sand. They are inferior inasmuch as they are usually rich in soluble salts and so tend to cause "scumming" (I. 193), though this is often unimportant in the case of common bricks.

"Soil"¹ and *Breeze* (I. 84), or finely sifted cinders are often used as a substitute for sand in the manufacture of bricks, especially in the south of England. This material reduces the shrinkage of the clay and acts in the same way as siliceous sand, and secures the formation of sound, well-shaped bricks; but as they tend to be very porous it is customary to mix sufficient chalk with the clay to produce enough fused material to make strong and hard bricks. "Soil" also serves, as a result of the fuel it contains, to assist in burning the bricks made with it. The proportion of "soil" used varies in different works, but as much as 20 tons of fine siftings of ashes are sometimes mixed with sufficient brick earth and chalk to make 100,000 bricks. Care must be taken with this material not to add too much to the clay, or the bricks may be overfired, whilst if too little is added the bricks may be underburned. The amount of "soil" which should be used in any given case must depend on the nature of the clay used and can only be learned by experience.

"Soil" is so unsavoury a material, and, owing to the cost of preparing it, is now so much more expensive than coke-dust or other better grades of fuel, that its use is gradually diminishing. It has, however, been used for many years and is still employed in the manufacture of the bricks known as "London Stocks."

Use of Sand in moulding Bricks.—Sand is used when moulding bricks by hand in order to prevent the clay from adhering to the mould and so to facilitate the ready removal of the brick. The sand used in moulding also appears to have a favourable influence on the resistance of the bricks to weather, though very few reliable data on this subject are available. The brick moulder works at a table provided with a deep iron rim at both ends and partly along one side to keep the sand in place. Sand is first sprinkled by an assistant, known as the clot moulder, on the bench so as to prevent the clay from adhering to this, and a rough brick or clot is made by shaping a mass of clay paste with the hands. The moulder sprinkles the "stock board" which forms the bottom of the mould with sand, quickly dashes the wooden mould box into the pile of sand and lays the sanded mould on the stock board. The clot is then forcibly thrown into the mould, any surplus clay is removed by means of a flat piece of wood or "strike"; the mould is then lifted and the brick allowed to slide gently out on to a pallet-board upon which it is conveyed to be dried. The mould is then re-sanded and the operation repeated.

In brick machines which are intended to imitate bricks made by hand moulding, the moulds are dipped in sand in the same way

¹ "Soil" must not be confused with the material known by that name in agriculture. "Soil" is an abbreviation of the term "night soil" and is the smallest particles of the material obtained from earth-closets.

each time the moulds are to be replaced in the machine, a sanding tank being placed for this purpose near the brick machine.

The natural colours of the various sands used for moulding bricks are not of great importance except as a means of identification. The colour of the sand after burning is, however, of great importance, as it affects the appearance of the bricks. Many of the sands in Yorkshire and Lancashire cannot be used for moulding bricks as they impart an unpleasant colour to the bricks. Some of the Bagshot sands (I. 81) and various sands from Essex are largely used on account of the pleasing red colour they produce on the bricks.

The sands used for sand-moulded bricks in the London area are largely obtained from the bed of the Thames near Woolwich, but other local beds are also employed.

The reddish and yellowish Triassic sands of Nottinghamshire, Leicestershire, and Warwickshire, and the brown Jurassic sands of Warwickshire are also used satisfactorily in moulding bricks.

Sea sand is used for moulding some of the hand-made bricks in Suffolk and Lincolnshire.

The sand used in moulding bricks should be moderately fine; it should not be coarser than 30-mesh nor much finer than 120-mesh. Its grade is specially important, as it exerts a considerable influence on the appearance of the finished articles. If too coarse a sand is used, the bricks will be rough and have pitted faces, whilst a sand which is finer than 120-mesh will usually contain too many rounded grains, which lack the necessary power of adhering to the clay. Sand for moulding should, in most cases, be rather finer than that used for mixing with the clay. The grains should be reasonably sharp and angular, as rounded grains lack "gripping power."

It is difficult to prescribe any tests whereby the suitability or otherwise of a sand for use in moulding bricks can be ascertained. This information is best obtained by allowing a practical brick moulder who is regularly using such sand to use it on a few hundred bricks, and to express his opinion of the result when the bricks have been drawn from the kiln.

Use of Sand for facing Bricks.—Sand-faced bricks are largely used, particularly in the south of England, for exterior work on account of their pleasing appearance, especially as regards colour, as well as their durability and resistance to weather. They are termed sand-faced bricks because their faces are coated with a thin layer of sand, which is applied at an early stage in their manufacture and remains adherent to them after they are drawn from the kiln.

In the case of hand-moulded bricks, the sand is applied during the moulding as previously described (p. 5), but in that of wire-cut bricks the sand is sprinkled on the column of clay as it issues from the brick machine. Sometimes the sand is pressed into the surface of the clay by a roller at the mouthpiece of the machine and sometimes the bricks are repressed so as to fix the sand to their surface.

The sand for this purpose is the same as that used in sand moulding (p. 6), the colour of the sand after burning being specially important. For red bricks, one of the best sands is that obtained from the Bagshot beds (I. 81), but any of the sands mentioned on p. 6 may be used for producing a pleasing red colour. For white and buff bricks, a white-burning sand such as the Calais sand is used. It must be sufficiently fine and angular, and fairly free from iron oxide so as not to discolour the bricks.

Use of Sand for producing specially shaped Bricks.—When the bricks of special shape are required for arches, etc., and also when they are required to be carved for monumental purposes, it is sometimes inconvenient to mould them to the required form, especially if the number of bricks of any one shape is quite small. An easy method of obtaining such bricks is to make them in the ordinary manner, using a loam very rich in sand or an artificial mixture of sand and clay, and afterwards cutting or rubbing the burned bricks until the desired pattern or shape is produced. To be suitable for this purpose the bricks must be soft enough to be readily cut or rubbed to the desired shape, and for obvious reasons are termed *cutter bricks* and *rubber bricks*; they are not so largely used now as formerly, as they have largely been replaced by pressed bricks of almost any desired shape; such bricks contain less sand and so are much more durable than the soft cutter and rubber bricks. There is no essential difference in composition between cutter and rubber bricks, and the same sand is used for both.

The difficulty experienced in obtaining sufficient quantities of natural earth suitable for cutter and rubber bricks has, for a long time, compelled most manufacturers to make them by adding a suitable proportion of sand to a washed brick earth. The addition of a large proportion of sand is necessary to produce bricks which will be of the same texture throughout, and so yield a uniform appearance after they have been shaped by rubbing or cutting, and to give them an agreeable face.

The sand for cutter and rubber bricks must be sharp and angular and of a moderately fine grain; it should not be coarser than 30-mesh nor finer than 120-mesh. After burning, the colour of the sand must be the same as that of the clay to which it is added. As white, red, and buff bricks are made, the sand used must be selected so that its colour after burning conforms to that of the kind of bricks to be made. Rubber and cutter bricks are usually red, and for this purpose a red-burning sand is used, such as those employed for moulding (p. 6). For white or buff bricks, some of the sands mentioned under sand-facing above may be used. The most suitable sands must usually be found by trial.

Uses of Sand in drying Bricks.—In drying, bricks are sometimes piled one above another to a height of about 8 bricks or courses, and, in order to prevent the adhesion of the bricks one to another, sand is usually sprinkled upon the top of each course before another one is placed upon it. The sand for this purpose should be the

8 PREPARATION OF SANDS FOR BRICK-MAKING

same as that used in moulding the bricks. The sand is seldom needed if the bricks are first dried singly on a warm floor or on boards on a car, but only when they are taken direct from the moulds or machine and piled on one another. Bricks made of a very stiff paste are less liable to adhere than those made of a softer paste, and do not usually require to be sprinkled with sand.*

Sand is sometimes dusted on to bricks laid singly on a drying floor so that any soluble salts, which would otherwise discolour the bricks, may be absorbed by the sand, and if this is brushed off before bricks are taken to the kiln they will be clean and free from scum. Grog or brick-dust, being more porous than sand, is often superior to it for this purpose.

Use of Sand for Glazed Bricks.—Sand is used in the preparation of the glazes for coating bricks for interiors, sanitary work, etc. The glaze consists of a mixture of felspar, pegmatite, whiting, and sometimes one or more metallic oxides together with silica or a pure sand which is added to increase the whiteness of the glaze, to provide the silica necessary to produce a clear, glossy glaze or glass, and to enable the glaze to adhere properly to the clay.

Flint is usually preferred to sand on account of the greater fineness to which it has been reduced by grinding, but a very fine and pure sand is sometimes equally satisfactory. The most suitable sands for glazes are those used in the manufacture of glass, which are fluxed together with various other materials to produce a homogeneous glass. This subject is dealt with more fully in Chapter XII.

Preparation of Sand for Brick-making.—The sand used for brick-making does not usually require any preparation. In some cases it may require to be sifted or screened by one of the devices mentioned in Vol. I. Chapter X. in order to free it from coarse matter, but unless the sand can be used without any serious amount of treatment it should usually be rejected, as the cost of treatment, in most cases, would be prohibitive.

The two exceptions to this statement are screening and drying the sand.

Screening is not expensive, and as it can be used to free the sand from excessively coarse material as well as unduly fine material, it should seldom be omitted.

Drying may be necessary if the sand is damp when it is obtained. It is often sufficient if the sand is merely spread out in the open air in thin layers which are repeatedly raked over so as to expose every particle to the air and especially to the sun's rays. This method can, of course, only be used when the climate is suitable; where it is not so, an artificial dryer must be employed, such as one of those described in Vol. I. p. 401. A hot floor is sometimes used, though it is not satisfactory for large outputs as the labour involved makes it more costly than a mechanically operated dryer. Other artificial methods of drying, such as those described in Vol. I. pp. 401-413, are satisfactory, but the cost of installation

will be prohibitive unless the quantity of sand to be dried is sufficiently large.

Testing.—Very few tests can be applied to sands which may be used in brick-making, and yet, if more care were taken, much better results might be obtained. The principal tests which should be applied are :

1. Cleanness (I. 244).
2. Chemical composition, where this is important, and especially the iron content (I. 237).
3. Texture, including the sharpness or angularity of the grains (I. 246).
4. Appearance and colour after burning in contact with the clay with which the sand is to be used.

LIME-SAND BRICKS

In many localities where clays and brick earths are scarce or unsuitable, bricks are made from a mixture of about 8 parts of lime, 85 parts of sand or crushed rock, and 7 parts of water, the essential feature of these bricks being that the lime and silica are combined during the process of manufacture to form hard, strong, and durable bricks, which have most of the advantages of bricks made of clay without some of their disadvantages.

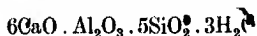
The method of manufacture was first patented in 1880 by W. Michaelis, who found that when mixtures of lime and silica were subjected to the action of steam under pressure, a hard, strong mass was produced. By making the sand and lime into the shape of bricks before hardening, a very satisfactory building material is produced, the bricks improving with age, though they can safely be used immediately after they leave the hardening chamber.

Lime-sand bricks have not become very popular in this country on account of the ready accessibility of ample supplies of clay, but they are very popular in Germany, Sweden, some parts of the United States, and in other countries where suitable clay is scarce, but suitable sand is abundant.

The exact composition of the compound of lime and silica formed is not definitely known; it was considered, at one time, to be a simple calcium silicate, CaH_2SiO_4 , with or without combined water, though now it is known to be much more complex. It is very difficult to isolate and examine this compound, but from experiments which have been made it appears to have the following composition :

Silica	.	.	.	43.1	per cent
Alumina	.	.	.	13.1	"
Lime	.	.	.	37.2	"
Water	.	.	.	6.5	"

which corresponds closely to the following formula or some multiple of it—



The amount of water which enters into combination varies greatly, but the composition of the best bond appears to approximate closely to that of Portland cement, though it is usually richer in silica than the latter. Attempts to prepare a definite compound of lime and silica for use as a binder have proved unsatisfactory, and the binding action appears to be due to a series of compounds each acting independently, the chief of which are colloidal silica, colloidal hydrated lime, and one or more complex calcium silicates which do not correspond precisely to any chemical formulæ, possibly because they are in the colloidal state. In the course of time, and especially on heating in the hardening chamber, these colloidal materials contract, harden, and thus tightly bind the particles of sand together.

The sands used in the manufacture of lime-sand bricks should occur near to where the bricks are made, as otherwise the cost of transportation may be excessive. There is a very large variety of sands which may be suitable for the manufacture of lime-sand bricks, including rock sands, river sands, sea sands, blown sands, etc., though some are preferable to others.

The ideal sand for making lime-sand bricks is one which consists of round or angular grains of silica with no loose impurities and containing a sufficient amount of very fine material to produce a sand with a minimum proportion of voids, the fine grains filling, as nearly as possible, all the interstices between the larger particles.

Sources of Sands.—Most sands of fair purity are suitable for the manufacture of lime-sand bricks, and they are available in so many localities that no list of their occurrences can be given here. As yet, few of these sands have been tried, but the Lower Greensand beds of Sussex and the Lower Eocene beds of Surrey, particularly at Beddington, have been used satisfactorily for this purpose.

Sands may also be made by crushing siliceous rocks, the best rocks for the purpose being pure quartz, or quartzites, which, when crushed, have properties almost identical with those of the purer sands. The cost of crushing is usually prohibitive. Quarry waste—which might, otherwise, involve a cost for tipping and storage—can be used in some cases quite satisfactorily.

Crushed rocks for use in the manufacture of lime-sand bricks should be specially examined to determine their suitability. Some consist of minute globular grains which have little or no felting or interlocking power, are deficient in surface area relative to their volume, and do not react readily with lime. Such grains are practically useless unless they can be mixed with some other more suitable material, in which case they form a cheap diluent rather than a desirable constituent of lime-sand bricks.

The chemical composition of the sand is not of very great importance, though the sand should preferably consist entirely of grains of quartz. The presence of other substances as impurities, if in large quantity, renders the sand of small value, as these substances will not produce a suitable silicate with the lime, and so will lessen the strength of the bricks. If, however, the grains of

foreign material are coated with silica, or are present as inclusions in the quartz grains, a comparatively large proportion of impurity may be present without doing any harm. Some sands which are relatively low in silica, provided that the silica completely envelops the grains of other material, sometimes prove to be quite satisfactory for the manufacture of lime-sand bricks. Hence, the chemical composition of the sand is of much less importance than the physical conditions and distribution of the constituents. The difference between suitable and unsuitable sands is shown in Figs. 1 and 2. In Fig. 2 the impurities are all inside the quartz and are therefore harmless, whilst in Fig. 1 they are outside and would, if made into bricks, give a weaker product. The suitability or otherwise of a sand can be ascertained to some extent by an examination of the material with a microscope (I. 241). The presence of very small



FIG. 1.—Unsuitable sand.



FIG. 2.—Useful sand.

grains of impurity in the interstices between the larger grains of quartz is not harmful, provided that the particles of impurity are extremely small and do not interfere with the uniform coating of the quartz grains by lime during the mixing process.

Whilst impure sands can be used for lime-sand bricks, if the impurities are covered as described, a pure sand is naturally to be preferred if it is available, especially as impure sands are seldom completely coated with silica. It is consequently risky to use very impure sands, and the material should be very carefully tested by an expert before any large amount of capital is expended in exploiting it.

From the foregoing statements it will be understood that the proportion of silica in the sand used—this being the factor upon which the purity of the material is usually based—gives but little guidance in deciding whether a given sand will be satisfactory in the manufacture of lime-sand bricks. In fact, it has been established that many sands which have been regarded as useless on account of their low silica content have been excellent when made into bricks, as their impurities have, fortunately, been sufficiently enveloped by a coating of silica and so rendered innocuous.

It has been stated that sands containing a large proportion of felspar are preferable to those consisting wholly of quartz on account of a mistaken idea that lime and felspar react more readily than

lime and quartz. This is, however, incorrect, and no sand is better for the purpose than one consisting of pure quartz.

It has also been suggested that a sand containing soluble silica, i.e. silica which is soluble in a strong solution of caustic soda (I. 204), should be preferred to one of pure quartz, as the soluble silica might be expected to react more readily with the lime. This is not found to be the case in practice, and if some of the sand is in a very finely ground condition, equally satisfactory results can be obtained; still, very finely ground quartz reacts readily with lime. Some years ago, the author made a number of tests on the use of soluble silica for lime-sand bricks and found that when pure sands were treated with caustic soda none of the silica was soluble, but when mixed to form lime-sand bricks, 5 per cent of the silica was attacked and combined. Thus, the lime is able to deal quite effectively with pure quartz and the presence or addition of soluble silica and amorphous silica is unnecessary. To secure the most effective results, however, it is necessary to employ some of the sand in a very finely divided state, as the author has found the sand grains between 25- and 36-mesh are not appreciably affected by the lime, even when they are exposed to the action of steam, under pressure, for three times as long as usual.

The cost of grinding the sand to a fine powder would be prohibitive and unnecessary, but a sufficient proportion of it must be very fine, so as to secure the effective combination of the lime and the sand. In some cases, the sand contains a sufficient quantity of very fine grains of quartz and does not require any special treatment; otherwise a portion of the sand may have to be ground specially fine or some other form of fine silica may have to be added. Finely ground flint and kieselguhr have been used to supply the fine silica necessary, but whilst satisfactory from a technical point of view, they are generally too costly to be employed.

The *effect of clay* in the sand is generally harmful, as the clay is liable to coat the sand grains and prevent the interaction between the latter and the lime. Consequently, the sand should usually be as free as possible from clay. Some manufacturers have found, however, that the presence of 2-3 per cent of clay is an advantage. This is probably due to the fact that a small quantity of clay introduces a little alumina into the complex calcium silicate and gives a bond which approaches Portland cement in composition and is, therefore, very strong. The presence of 2 per cent of pure clay in a sand will introduce 0.7 per cent of alumina, and this is all that is required for 6.5 per cent of lime.

To a certain extent the fine clay particles act in the same way as the smaller particles of silica and aid in the binding together of the larger particles, and for this reason the presence of a little clay in a coarser sand which requires the addition of fine particles may not be harmful, but the addition of clay is less satisfactory than the addition of fine particles of sand, which have all the advantages without the drawbacks of clay.

The effect of the presence of small quantities of clay is very difficult to ascertain, but larger proportions of clay are always harmful, since the clay particles, being extremely fine, are attacked by the lime much more readily than are the coarser grains of silica, so that if there is more clay than the lime is able to neutralise, the resultant bricks will be weak and imperfectly bonded together. For this reason, sands containing clay, if used at all, require the presence of a larger proportion of lime than clay-free sand. This fact has been confirmed by the experiments of Michaelis and independently by those of Glasenapp.

It is not generally desirable to wash sands for making lime-sand bricks in order to remove the clay, as in doing so some of the finest grains of silica will be lost at the same time, and the removal of these fine grains may be more harmful to the material than the presence of the small proportion of clay. If the sand is so impure that washing is imperative, it may be necessary to add a small proportion of fine silica to the washed sand, in order to restore the necessary quantity of fine grains to fill up the voids between the larger particles.

Limestone dust and chalk are objectionable in the sand, as they coat the grains with an inert material and prevent the formation of a proper bond.

Organic matter should not be present, as it prevents the interaction between the lime and sand.

Soluble salts should not be present in the sand, as the bricks made from a salty sand are liable to scum badly and so have an unpleasant appearance. The action of salt is, however, rather uncertain, and in some cases salty sands from the seashore have been used extensively without any difficulty arising, though it is generally better to avoid such sands. Dune sands which have been well washed by the rain are quite satisfactory, as most of the soluble salts have been removed in solution.

Ferruginous matter in the sand is not of great importance unless bricks of special colour are desired. The lime used in making the bricks tends to mask the brown or red colour of the iron compounds, so that whilst a pure white sand is the best, the presence of a small percentage of iron compounds is not harmful, especially if the grains of ferruginous matter are coated over with silica. This may be determined by examination under a microscope.

The texture of the sand used for lime-sand bricks is very important, even more so, in some respects, than the chemical composition. The grains may be either round or angular, but they must not be flat or flaky, as are micaceous sands. The relative values of rounded and angular grains are a matter of some controversy, though in some ways rounded grains are preferable; they roll so easily together and so render the amount of voids as small as possible, whilst angular grains tend to form larger interstices, though in some cases they interlock and reduce the size of the voids. As a general rule, however, sharply angular

grains tend to produce a weaker brick than one made with sub-angular or almost round grains of sand. Sharp-grained sands often require a large proportion of lime on account of the greater percentage of voids present. Excessively rounded grains, on the other hand, are undesirable, as they are difficult to use and do not bind well. If they must be employed, and the sand is sufficiently coarse, it may be necessary to grind about 25 per cent of the sand so as to produce a sufficient quantity of sharp material.

The size of the sand grains, as has already been mentioned, is of great importance, as the lime will only react satisfactorily with the finest grains. Yet the grains should not all be fine, as grains of several different sizes are required to produce the most satisfactory bricks. The ideal sand should contain no grains which remain on a 20-mesh sieve, but should be composed of grains of such various sizes that the smaller ones fill the interstices between the larger ones. When all the grains are mixed together, the final interstices should be such that after mixing the sand with lime each particle of sand is coated with a film of lime and no voids are left. To ensure this, it is necessary to use a sand consisting of grains of many different sizes. Sands composed of grains of only one size—no matter whether they are large or small—do not pack so closely together as those composed of grains of various sizes.

An excessive proportion of large grains is undesirable, because large grains produce large and numerous voids and there will not be a sufficient number of points of contact between the various grains; consequently, the bricks will be weak.

Under ordinary circumstances, at least 12 per cent, but not more than 15 per cent, of the sand should pass through a 100-mesh sieve, and of this about one-third should pass through a 200-mesh sieve. This will provide a sufficient proportion of the finest grains; an excessive proportion is undesirable, as they will tend to produce weak bricks, because the fine grains have a much larger surface in comparison to their bulk than coarser grains, and so require a larger proportion of lime to coat them. Moreover, finely ground sands are often badly graded and require a larger proportion of lime to fill the voids. They also contain a large volume of air which is extremely difficult to displace.

There is also another difficulty, due to the fact that the finest grains and all the material which passes through a 200-sieve will generally contain all the clay and much of the other impurity in the sand, and if this is in a large proportion the sand will have to be washed before use. If, however, the proportion of clay and other fine-grained impurities is not more than 4.5 per cent, little harm will be done, and there is then no necessity to wash the sand.

Sands which contain grains of unsuitable size, or in which the grains are too uniform in size, may be greatly improved by screening out the unduly coarse grains and by adding rock or sand which

has been ground and screened so as to contain grains of the sizes in which the original sand is deficient. Thus, where the addition of a quantity of coarser grains is essential, it may be supplied either by the addition of a sand containing a sufficient quantity of coarse grains or a suitable proportion of crushed rock may be added to the sand.

Where there is an insufficient proportion of fine grains, silica flour must be added. This is produced by grinding some of the sand until not more than 20 per cent of residue is left on a 200-mesh sieve. A ball mill, pendulum mill, or a tube mill is the most satisfactory machine for this purpose (see Vol. I. Chapter VIII.).

The effect of the size and grading of the sand used for lime-sand bricks is shown in the following Tables I. and II., due to Peppel. Bricks were made of two sands of the composition shown in Table I. in various proportions, 5 per cent of lime being used in each case.

TABLE I.—GRAIN-SIZES OF TWO SANDS

	20-40 Mesh.	40-60 Mesh.	60-80 Mesh.	80-100 Mesh.	100-120 Mesh.	120-150 Mesh.	150-200 Mesh.	Passing 200 Mesh.
Coarse sand	50	33	7	7	2	1	..	..
Fine sand	..	..	..	..	0.7	1	1.25	97.05

The strengths of the resultant bricks are shown in Table II.

TABLE II.—EFFECT OF FINENESS OF SAND

Composition of Mixture.		Crushing Strength, lb. per sq. in.	Tensile Strength, lb. per sq. in.
Coarse Sand.	Fine Sand.		
8	2	3114	131
4	2	2955	144
3	2	2461	224

It will be seen that the larger the proportion of fine sand the weaker are the bricks. Some fine sand is necessary, however, to secure effective combination with the lime; if present in much more than this proportion very fine sand is a source of weakness.

One of the best methods of comparing sands as to their suitability for making lime-sand bricks is to find the proportion of different sizes of grains and plot them in the form of a graph, using the method employed by Boswell (I. 225). A sand which has no

grading, i.e. in which all the grains are of the same size, will be represented by a vertical line, whilst the greater the grading, the rounder and smoother will be the curve. The best materials are those which produce a smooth round curve.

The comparison of materials for lime-sand bricks may also be made by means of the surface factor as described in Vol. I. p. 211, and also on p. 38 in connection with the grading of sands for concrete.

It should be realised that the grading of the sand is of great importance if the best and strongest bricks are to be obtained, so that the sand should be frequently and carefully tested for fineness as described in Vol. I. p. 246; if the grading of the sand is not suitable, a sufficient quantity of grains of other sizes must be added until a suitable grade is obtained. This testing is equally as important in the ordinary course of manufacture as in selecting a supply of sand.

The voids in a sand used for lime-sand bricks should be such as to give the strongest possible bricks consistent with sufficient porosity to prevent the interior of houses built of the bricks from "sweating" or "condensation" on the interior walls. The proportion of voids depends largely on the grading of the sand and on the selection of grains of sufficiently varied sizes. As climatic conditions vary in different localities, no very definite rule can be given as to the best proportion of voids, but, in general, there should not be less than 8 per cent nor more than 20 per cent of voids except in unusual circumstances. The smallest proportion attainable, with a minimum of 8 per cent, is generally found to be most satisfactory. Careful attention to the proportion of voids and to the sieve-tests of the sand during the ordinary course of manufacture will save much trouble and loss in the manufacture of lime-sand bricks.

The sand should be dry when used, as, if an unknown amount of water is present in the sand, it is impossible to know how much more should be added. If too little water is present in the mixture of lime and sand, the lime will not be properly slaked, and as a result the bricks will be weak and will crack and "blow" when in use. If too much water is present in the mixture (as a result of using wet sand) the mixture will be too soft and the bricks will not be properly pressed. A skilled pressman can tell by observation whether the mixture is too wet, so that the amount of water to be added is usually decided by him, and notwithstanding the great importance of using dry sand, this material is seldom dried, as the cost of doing so is in most cases regarded as prohibitive (but see p. 17).

The lime-sand brick industry has suffered greatly in many localities from the lack of knowledge on the part of those who have attempted to make bricks by this process, as the method, though simple to a skilled man, is not so simple as some people suppose.

SANDS FOR LIME-SAND BRICKS

Preparation of Sand for Lime-sand Bricks.—The object of the manufacturer of lime-sand bricks should be to secure a sand which needs as little preparation as possible, as any such treatment increases the cost of manufacture. Most sands require some preparation before they can be used, but it should be reduced to a minimum.

Washing, if more than about 3 per cent of clay is present in the sand, is generally desirable, though sometimes even with this proportion it is not necessary. Bricks have been made with sand containing as much as 20 per cent of clay, though usually it is preferable to wash such a sand. The loss of fine silica grains which are carried off with the clay during the washing should be replaced by the addition of a suitable proportion of silica flour.

The washing may be effected by whichever of the methods described in Vol. I. p. 384 may be most suitable to local conditions. The Freygang apparatus and others of a similar nature are very satisfactory for removing small proportions of clay and other fine materials, and as they permit a very accurate separation to be made, a minimum of valuable material is lost. As washing is generally a costly process, it should be avoided as far as possible (see p. 12).

Drying is not usually necessary unless the sand contains more than 8 per cent of water. It is generally sufficient to spread the sand out on a sloping bed of concrete or wood and to expose it to the air for a few days. Where this is not sufficient, some form of artificial dryer must be used (I. 401), though it will usually be found that the cost of its installation is prohibitive. One of the most economical and satisfactory types of dryer for this purpose is a rotary dryer (I. 410), in which the sand can be heated by flue gases in an inclined drum or cylinder provided with paddles.

Grinding.—Where there is not a sufficiently large proportion of fine grains, some silica flour or its equivalent must be added. This is usually made by grinding part of the sand to a fine powder.

Where bricks are made of sandstone, the whole must be ground to pass through a 20-mesh sieve, and a small part of it further reduced, if necessary, to produce a sufficient quantity of the finest grains.

Rocks should preferably be broken down to pieces not more than 1 in. diameter either by hammers or in a jaw-crusher (I. 347) or disintegrator (I. 352), and the product then ground, if necessary, in an edge-runner mill (I. 374). The last-named must not be fed with pieces which are too large, or the grinding will be unduly costly. Some sandstones can be reduced to a suitable size in a jaw-crusher followed by a disintegrator, without an edge-runner mill being needed.

The supply of finest grains can best be obtained by grinding a portion of the material in a ball mill (I. 365), pendulum mill (I. 371), tubo mill (I. 369), or similar fine-grinding machine.

Screening.—After crushing, the sand should be screened, a per-

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forated plate (I. 447) having $\frac{1}{4}$ -in. holes, or a gauze screen (I. 444) being generally the most satisfactory for the purpose. Even when no crushing is necessary, it is still wise to screen the sand. Sometimes, if a sand contains pebbles or other coarse material, it may be best to screen and separate the coarse particles rather than grind the sand.

If the sand is at all damp, a vibrating screen (I. 449) may be necessary in order to prevent the clogging of the meshes.

In some cases, several screens are necessary, in order to divide the sand into a number of different grades or sizes, which can afterwards be remixed in suitable proportions. Although this procedure is essential in some cases, it should be avoided as far as possible, as a mechanical mixer cannot produce so uniform a material as a natural sand.

The screening must be very carefully carried out, since upon it largely depends the final strength of the bricks. Imperfect screening, and especially imperfect grading, may lead to serious results. The screened material should always be carefully tested for fineness (I. 246) so as to ensure that it is suitably graded.

Testing.—The testing of sand for use in making lime-sand bricks is most important and should preferably be done by experts, as ordinary analytical chemists have neither the necessary appliances nor the special knowledge required. The tests are especially necessary before starting a new works, as failure may result from the use of unsuitable material. They should also be repeated at intervals in order to maintain a constant product.

The collection of samples for tests should be carried out as described in Vol. I. p. 235.

The principal tests necessary are :

1. Determination of the percentage of moisture (I. 238).
2. Determination of the percentage of silica (I. 238).
3. Determination of the loss on ignition (I. 239).
4. Determination of the percentage of silt (I. 250).
5. Determination of the percentage of clay (I. 245).
6. Determination of other impurities (this is not often necessary).
7. Determination of the percentage of voids (I. 261).
8. Determination of fineness and grain size (I. 246).
9. Microscopic examination (I. 241).

Defects caused by unsuitable Raw Materials.—*Absorption.*—If the bricks are excessively porous, the cause should be first sought in the imperfect grading of the material, which will cause too large a proportion of coarse grains to be present, together with an insufficient quantity of fine grains to fill up the interstices between them. The remedy for this defect obviously consists in correcting the grading of the sand, as described on p. 14. Other causes of excessive absorption which have nothing to do with the sand need not be described here.

Blotches or discolorations in the bricks may be due to the use of

unsuitable sand containing an excessive proportion of coloured impurities. Discoloration may also be due to the presence of soluble salts in the sand, which produce a white scum or "pest" on the surface of the bricks. Sea sand frequently forms a white scum due to the salt present in it. The remedy is to avoid the use of such sands because of these defects.

Chipping or spalling is sometimes produced in lime-sand bricks by the use of sand of irregular composition or of imperfectly mixed materials. This results in the outside of the bricks being different from the interior and so setting up stresses which cause the disintegration of the bricks.

Cracks are sometimes due to the use of an unsuitable sand, though more often they are the result of some error in manufacture.

Dusting is sometimes caused by the presence of fine impurities in the sand. These are not cemented in the hardening process and gradually come off as a fine dust. Scum caused by soluble salts (see above) should not be confused with "dusting."

Irregularity in texture is due to bad grading and also to imperfect methods of manufacture.

Weakness is often due to the use of a badly graded sand, though the method of manufacture may have much to do with the final strength of the bricks.

Further particulars respecting the manufacture of lime-sand bricks will be found in the author's *Bricks and Artificial Stones of Non-plastic Materials* (Churchill).

ARTIFICIAL STONE

Artificial stone is similar to lime-sand bricks, except that materials other than sand are sometimes used as an aggregate and materials other than lime are often used as bonding agents. The nature of the "stone" and the method of manufacture are, however, very similar.

Crushed rocks (chiefly composed of quartz) and sand have been used for making artificial stone since 1860, when F. Ransome first made bricks by mixing one part of sodium silicate with 18 parts of crushed quartz, the pasty mass being moulded to the desired shape and then immersed for several weeks in a solution of calcium chloride. This caused the decomposition of the sodium silicate with the production of a complex calcium silicate and common salt. This silicate acts as a binding agent and firmly bonds together the particles of quartz. The common salt is dissolved out by immersing the bricks in a stream of running water for a sufficient time. Such bricks had a crushing strength of 7000 to 12,000 lb. per sq. in., but the process was never commercially profitable as the reaction between the calcium chloride and the sodium silicate is not complete, especially in the centre of the bricks, and as the salt cannot be completely washed out, the effect of rain on the bricks gives them an unpleasant appearance.

Ford's stone is usually classed as an artificial stone, though it is simply a lime-sand brick consisting of a 92-95 parts of sand and 5-8 parts lime, made into bricks and hardened with super-heated steam. The properties of the stone are identical with those of lime-sand bricks.

Victoria stone, Imperial stone, Empire stone, Indurated stone, etc., are artificial stones prepared by uniting particles of sand or crushed rock with Portland cement or sodium silicate. The sand used for these stones should have the same characteristics as that employed for lime-sand bricks. In some cases the sand is only used as a facing for the artificial stone, the centre of the blocks consisting of crushed stone or other coarse material.

Some artificial stones are made from a mixture of 4-5 parts of sand or crushed stone and 1 part of molten pitch.

Mortar bricks are artificial stones made by mixing slaked lime and sand and allowing them to stand for 6-18 months in the open until a hard cement is formed by the action of the carbon-dioxide in the atmosphere on the slaked lime and by the interaction between the lime compounds, silica and water. These bricks are now little used and have been superseded by lime-sand bricks and by concrete.

Sorel stone is made from a mixture of sand or other inert material and magnesium oxychloride commonly known as Sorel cement. Unfortunately, the cement is affected by water, so that Sorel stone is not very suitable for outside work; for interiors it is extensively used.

Further information on artificial stones will be found in the author's *Bricks and Artificial Stones of Non-plastic Materials* (Churchill).

LIGHT OR POROUS BRICKS AND INSULATING MATERIALS

Light bricks of very high porosity and extensively used for insulating walls, etc., are made by the addition of kieselguhr or diatomaceous earth (I. 96) or sand to the clay used for making the bricks. The manufacture of such bricks was known in very ancient times, but it was completely lost until the close of the 18th century, when M. Fabbri rediscovered the method and used an Italian diatomaceous earth for the purpose. The so-called "floating bricks" may weigh only one-sixth as much as ordinary clay bricks, and are largely used on the Continent for insulating bricks, sound-proof partitions, etc.

Sources.—The chief sources of kieselguhr and diatomaceous sands are given in Vol. I. p. 96, where the properties of these materials are also described.

Pumice (I. 137) has also been used on the Continent for making light or "floating bricks," the powdered pumice being bound with a suitable proportion of lime or clay.

Properties of Materials.—The materials used for the manufacture of these bricks must be sufficiently pure to produce articles of the

requisite lightness. Where any particular colour is desired, the material must not contain any impurities which would prevent this colour being obtained.

Most commercial kieselguhr and similar diatomaceous sands are sufficiently pure for this purpose, as the requirements are not stringent. In making kieselguhr bricks, the lighter coloured varieties are generally preferable, the best being pure white or a light cream colour. The size of the grains is a matter of little consequence in the case of porous materials like kieselguhr, pumice, etc., as it is not controllable. The principal requirement is that the material should be extremely porous; this is not difficult to obtain with a reasonably pure material, as each microscopic grain is a hollow siliceous skeleton, with walls of extreme tenuity.

Preparation of Materials.—Little preparation is needed to render kieselguhr and allied materials suitable for brick-making. It is dug out in blocks and allowed to stand in the open to dry as described in Vol. I. p. 100. If necessary, the material may be calcined, and ground in a disintegrator (I. 352) or some form of fine-grinding mill (I. 363).

Pumice is generally obtained in pieces varying in size which should be freed from obvious impurities by hand-picking, and ground in a disintegrator (I. 352) or fine-grinding mill (I. 363) before use. No other preparation is necessary.

Testing.—The tests to be applied to materials for making light-weight bricks depend chiefly on the use to which they are to be put. The chief test in any case is *porosity* (I. 261), as the percentage of voids is the determining factor in the weight of the bricks.

Other tests which may be necessary for special purposes are :

- (1) Refractoriness (I. 260).
- (2) Chemical composition (I. 237).

REFRACTORY BRICKS

Refractory bricks such as silica bricks, ganister bricks, etc., are made from sands or crushed rocks in a similar manner to ordinary bricks, but they possess the quality of being able to resist high temperatures, so that they are suitable for the construction of (and for lining) furnaces and other appliances in which very high temperatures are reached. Such bricks are more conveniently dealt with in Chapter VII.

CHAPTER 11

THE USE OF SANDS IN CONCRETE

CONCRETE is a widely used building material which consists of particles of inert non-plastic substance united by a cement to form a hard, stony mass useful for all the ordinary purposes for which natural building stones are employed, and having special advantages in the construction of bridges, breakwaters, docks, canals, dams, reservoirs, etc. Its use has extended enormously and each year new uses are made of it.

The non-plastic material which forms the greater part of the concrete consists chiefly of broken stone or equivalent material, usually referred to as *coarse aggregate*, and *sand* of different degrees of fineness, termed *fine aggregate*, so that concrete may be said to be composed of four constituents: (a) cement, (b) coarse aggregate, (c) sand, and (d) water.

The apparent simplicity of concrete as a building material is the cause of much slipshod practice in its preparation, and many builders and contractors have developed the erroneous idea that any kind of material may be used with satisfactory results. This is quite wrong, as in order to prepare a concrete of best quality, great care must be taken both in the selection of the materials and in the actual methods of preparation. It is, however, only proposed to deal here with the sand used in its composition, other details as to the cement, coarse aggregate, and process of manufacture being fully dealt with in text-books dealing specifically with the preparation and uses of concrete.

At the same time, in order fully to understand what characteristics are required in the sand used for concrete, it is well to consider briefly the uses of various constituents employed. The broken stone or coarse aggregate forms the bulk of the concrete and between the pieces of stone are interstices or voids of considerable size. These voids must be filled with coarse sand, leaving a product with smaller voids, which must in turn be filled with successively smaller sand grains, so as to reduce the proportion of voids in the mixture to a minimum and thereby produce a dense and compact mass. The whole of the particles in this mixture are bonded together by means of the much smaller particles, of cement,

practically all of which are less than 200-mesh. Being very minute and of a plastic nature when wetted, the particles of cement coat those of the non-plastic material and fill any interstices in the mixture, so that if the coarse aggregate and sand have been properly graded and rightly proportioned, the resulting concrete is quite impervious to water. The wet, pasty material must be thoroughly mixed so that all the constituents are uniformly distributed and each piece of stone and each particle of sand are properly coated with cement. The mixture is then cast, moulded, or trowelled into the desired shape, and after it has been allowed to harden for a sufficient time—preferably being kept well wetted—the cement sets hard, firmly binds together the particles of non-plastic material and forms a strong, hard and dense “stone.” Much of the concrete now in use does not possess this impermeability, but is, on the contrary, quite porous; this is due chiefly to lack of care and skill in grading the aggregate and sand, and partly to an unwillingness to incur the expense involved in such grading and proportioning. In many instances, concrete of the best and densest quality is not required, and a much more roughly prepared material is quite satisfactory, as well as cheap.

The chief purposes of the sand are: (i.) to fill the interstices between the larger pieces of stone so as to produce a strong mass, and (ii.) to reduce the amount of cement which would otherwise be necessary to fill all the interstices. The sand is equally as efficient a filler as the cement, and is not only cheaper but eliminates other difficulties which are caused when an excess of cement is used.

Sources of Sand for Concrete.—A natural sand is usually employed to provide the fine non-plastic material in concrete. Such sands are widely distributed and ample supplies are usually available, either in the beds of rivers or lakes, on the sea-shore, or in pits sunk into sedimentary strata consisting of loose sandy beds.

They may be divided into four classes: (a) siliceous, (b) calcareous, (c) artificial, and (d) pozzuolanic sands. The siliceous sands are used much more extensively than any other, the best qualities consisting almost entirely of grains of pure quartz in rounded, subangular, or sharp grains.

Siliceous sands may be derived from any of the following sources: (a) pit sand, (b) river sand, (c) sea sand, (d) crushed rock.

Pit sand, provided it is sharp, clean, and free from gravel, clay, and other objectionable materials, is excellent for concrete. Some pit sands can be made suitable by screening or washing or by both these treatments. Much of the sand obtained from pits was originally deposited by rivers or lakes and should, therefore, be regarded as fluvial (I. 104) or lacustrine (I. 124); pit sand of marine origin is usually less suitable for concrete, as the grains are more rounded and worn smooth, and the presence of soluble salts in some of these sands is objectionable.

River or lake sand, when freshly dredged, is often more satis-

factory for concrete, than sand which is quarried, as it is generally cleaner and less contaminated by clay and dirt.

Sea sand is not generally suitable for making concrete unless it has been thoroughly washed, on account of the soluble salts usually present which tend to form a white scum on the surface of the concrete, and also to retard the setting of the Portland cement. At first, and for a month or two after making, the strength of concrete made with sea water or of concrete made with a sand containing soluble salts is less than that made from materials which do not contain any soluble salts, but after nine to twelve months the strength is approximately the same. Where the concrete is to be used in sea water, sands of marine origin and containing soluble salts may be quite satisfactory, as the appearance of the surface of the concrete is not of first importance. An undue proportion of soluble salts should, however, be avoided.

Glacial sands are not very satisfactory for concrete as they frequently contain a considerable proportion of felspar, calcium carbonate, and heavy minerals.

Crushed stone is sometimes used instead of sand, and if a good hard stone is reduced to particles of suitable size and properly screened and graded, it may be used with perfectly satisfactory results, its only disadvantage being the cost of crushing and screening it. For some purposes, it is even preferable to use a natural ungraded sand, as a well-graded sand produces a denser and, therefore, more waterproof concrete.

Some failures have occurred as a result of using unsuitable stone as a substitute for natural sand, but these do not occur when a hard siliceous stone is used. Portland stone is also used quite satisfactorily, but it is most undesirable to use mixed chippings and dust from masons' yards, as the true nature of such material is not always known and it may produce an unduly weak concrete.

Granite sands are also very satisfactory, and in Devon, Cornwall, and Wales are largely used for making concrete. In Devon and Cornwall, they are derived from the decomposed granites of the china clay areas, whilst in Wales the siftings from the granite crushing plants are employed.

Diorite and gabbro rocks, and many metamorphic rocks such as *granite-gneisses*, *schists*, etc., provide very satisfactory sands for concrete, except where they are contaminated by mica and altered felspar. Materials containing these substances should not be employed as concrete sands for reasons indicated on p. 30.

Calcareous sands do not generally occur naturally in a sufficiently pure state to be used in the preparation of concrete, but they are sometimes prepared by crushing limestone rocks to a fine powder, though such a practice is only useful in cases where the cost of crushing the material is not prohibitive. Apart from this, the use of calcareous material for concrete is satisfactory.

According to Taylor and Thompson, sands consisting of fine limestone screenings may develop a strength of 50,100 per. cent

greater than that of ordinary sand, though the final strength is attained rather more slowly than with the latter. The cause of this difference is not fully known.

Artificial sands are made by crushing rocks or other massive materials and so reducing them to "sand." Almost all sandstones and many other highly siliceous rocks may be crushed for this purpose, though sand made by crushing larger crystals of quartz is not generally suitable for concrete making, as it produces highly angular particles which give an excessive proportion of voids. *Flint* also gives angular grains and, therefore, an undesirably high proportion of voids.

Crushed volcanic scoriae, such as *pumice*, are very useful as a sand for light-weight concretes where the aggregate is made of larger pieces of the same material. According to J. P. Nash such concrete weighs 14.8 per cent less, is 12.5 stronger than where limestone is used, and has about the same strength as a sandstone concrete. *Pumice* also has the advantage of not "flying" when heated, like granite, flint, and similar rocks.

Cinders also render concrete very light, but are not a reliable material where great strength is required.

Iron ore tailings have been used very satisfactorily as a substitute for sand in concrete; they are usually well graded and produce a strong mass.

Pozzuolana (I. 136) or *trass* (I. 165) is sometimes ground to a fine powder and used as a sand. Pozzuolanic sands are especially valuable, as they not only act as a filler of interstices or voids, but, in addition, they combine with the lime set free when the Portland cement is wetted and so produce a pozzuolanic cement which aids in binding the particles of non-plastic materials together, and thus forms a stronger concrete than when an entirely inert sand is employed. This fact was well known to the ancient Romans, who mixed pozzuolana or trass (or, failing these, ground potsherds) with their mortar to increase its strength.

The value of a material of this kind is specially important as it neutralises one of the most serious defects possessed by Portland cement, namely the liberation of free lime, which if the concrete is subjected to the action of water as in piers and breakwaters, bridges, etc., is, in time, washed out and leaves a porous mass, in which the liability of the reinforcement to corrosion is considerably increased and the life of the structure is shortened in proportion to the increase in porosity. By employing some active material such as a pozzuolanic sand, which combines with the lime thus liberated, this defect is avoided and the porosity of the concrete is not diminished. For this reason it is very desirable to add rather more pozzuolana or trass than is necessary to combine with the whole of the lime liberated during the hydration of the cement; thus, lime usually weighs about one-quarter of the cement used, so that a suitable proportion of pozzuolana or trass is about one-half the quantity of Portland cement in the concrete; this amount may be

deducted from the total quantity of ordinary siliceous sand which would otherwise be used. A concrete consisting of 1 measure of cement, $\frac{1}{2}$ measure of trass, and 5 measures of sand and aggregate, has been found to be particularly durable and resistant to the action of sea water.

When natural pozzuolana or trass of sufficiently good quality cannot be obtained, a sand made by grinding lightly-burned clay may be substituted. Indeed, if the clay is reasonably pure and has been suitably calcined, such a product will be more active than the natural pozzuolana. Where specially calcined clay is not available, any other burned clay material which has been crushed to a suitable fineness may be used. Bricks, terra-cotta, grog, or other waste materials of the same character have been used for this purpose; they are not as good as clay specially burned for the purpose, as they have usually been heated to too high a temperature and so contain a smaller proportion of active material. If, however, a correspondingly larger proportion is used they are satisfactory. The cost of these pozzuolana substitutes is the chief drawback, though this is of minor importance in extensive maritime works.

A prepared sand consisting partly of inert material and partly of pozzuolana or its equivalent is nearly ideal and produces a highly satisfactory concrete, particularly suitable for use in sea water, where the conditions are most stringent. Pozzuolana decreases the hardness of concrete, but it increases the toughness and impermeability, and reduces the tendency to brittleness. Like pumice, pozzuolana and its substitutes are fire-resisting and do not fly when heated to a high temperature.

In spite of the great advantages which accrue from the use of pozzuolana in concrete, it has not been employed so much as its peculiar properties warrant; this is largely due to the fact that pozzuolana is not readily obtainable and is somewhat costly, and to ignorance of the fact that calcined clay is an excellent substitute.

Slag sand is prepared by running molten slag into water to granulate it and then crushing it; it is sometimes used in place of natural sand.

Ground glass and metal filings have also been used as sands in concrete.

The **chemical composition** of sands used in the preparation of concrete is not of great importance provided they are not too impure. As previously stated above, an ideal sand is composed of an active lime-absorbent with an inert filler, but where a natural sand is used the chief object, so far as chemical composition is concerned, should be to select a sand which is clean and not contaminated with clay, loam or "dirt." "The loamy or clayey matter found in many sands contains organic matter as well as clay, which is injurious to Portland cement, and is, therefore, a very undesirable constituent of concrete. Such sands may often be recognised by their dull or "dead" appearance, this being frequently, though

not invariably, due to the grains being coated with organic impurities.

Table III., due to S. E. Thompson, shows the effect of organic impurities in the sand. According to this investigator, the maximum allowable proportion of organic matter in a sand to be used for concrete is 0.1 per cent.

TABLE III.—EFFECT OF ORGANIC MATTER IN SAND

Sand.	Tensile Strength of 1:3 Mortar at 7 Days, lb. per sq. in.	Tensile Strength of 1:3 Mortar at 28 Days, lb. per sq. in.
0.5 per cent vegetable matter . . .	4	93
Average sand	43	114
Washed sand	129	201
Nearly free from organic matter . . .	165	..
Standard Ottawa sand	200	300

With regard to the effect of loam containing organic matter (probably humus), M. Feret has found that the strength of a 1:2 mixture of cement and sand was reduced by 2 per cent of loam, but that of a 1:3 mixture was slightly increased when 2 per cent of loam was added. It appears, therefore, that loam is more undesirable in strong mixtures of concrete than in weaker ones, though too much reliance should not be placed on a single set of experiments. Table IV., prepared by the Cement Users' Testing Association, shows the effect of loam on various sands which were passed through a 30-mesh sieve and were mixed with cement in the proportion of 1 part of cement to 2 of sand.

TABLE IV.—EFFECT OF LOAM IN CONCRETE

	Ultimate Tensile Strength after 2 Months in lb. per sq. in.	
	Unwashed Sand.	Washed Sand.
Sand from Newbury	430.2	430.2
Sea sand	307	308
Sand from Nuneaton	265	320

It will be seen that the first two contain very little loam and are not improved by washing, but the Nuneaton sand is considerably improved by having the loam removed.

The effect of clay, as distinct from loam containing organic matter, on the strength of concrete is by no means fully under-

stood. Some users of concrete consider the presence of clay in any proportion to be very undesirable, for the reason that it increases the amount of cement required and decreases the strength of the finished concrete. On the other hand, it appears that under certain circumstances clay is useful in concrete, and Seger and Cramer have found that clay sometimes increases both the tensile and compression strengths of the concrete. Their tests were made with a mixture of Portland cement mixed with three times its weight of suitable ("standard") sand, and similar mixtures were also prepared in which part of the sand was replaced by an equal weight of clay. Various clays were used for this purpose, the mixtures containing sand and clay in the ratio of 9 : 1. Each mixture was well stirred up with the water necessary to make the concrete and was poured rapidly over the cement, and the whole rapidly worked up in a small mixing mill in accordance with the German standard method of making tests. A number of cubes were then prepared in a Böhme hammer-mould, half the cubes being allowed to harden in water and half in air. The strengths of the test pieces were determined after one, three, and six months, respectively. The results given in Table V. are the averages of ten tests on each mixture :

TABLE V.—EFFECT OF CLAY ON CONCRETE

Mixture used.	Hardened in	Strength in lb. per sq. in. after					
		1 Month.		3 Months.		6 Months.	
		Tensile.	Compression.	Tensile.	Compression.	Tensile.	Compression.
1 of cement, 3 of sand.	Air	298	2489	424	3314	400	3573
	Water	253	2029	291	2610	328	3354
1 of cement, 2.7 of sand, 0.3 of china clay.	Air	395	2320	605	3382	577	3453
	Water	300	1995	333	2842	408	3555
1 of cement, 2.7 of sand, 0.3 of brick clay.	Air	372	2250	441	3212	428	3632
	Water	233	1780	310	2712	428	4010
1 of cement,* 2.7 of sand, 0.3 of sand ground as fine as possible.	Air	412	2447	420	3350	624	4255
	Water	350	2261	387	2735	467	3570

The increase in the tensile tests with the china clay is remarkable, and whilst the increase in strength brought about by the use of ordinary brick clay is less, it is still noteworthy and is more noticeable after six months hardening under water.

The tests made with exceedingly fine sand indicate that the action of the clay is due to its fineness rather than to any particular qualities which differentiate it from the sand.

A further set of experiments, in which the blocks were repeatedly frozen and thawed before testing, showed that whilst the samples containing the clay had a somewhat lesser strength than those in which pure sand was used during the first month, yet, when more completely hardened, the presence of as much as 20 per cent of brick clay considerably increased the strength of the test blocks, though after a year's exposure the pure sand showed better results than the clay mixture. The difference was so small, however, as to be scarcely appreciable, and may be well within the errors of experiment.

Further tests with large-sized particles of quartz replacing part of the sand showed that, in this case also, the presence of 10-20 per cent of moderately plastic clay had no perceptibly harmful influence on the strength of the concrete, either before or after the test pieces had been frozen repeatedly.

According to J. L. Davis, clay may be added to ordinary concrete with beneficial results in permeability and strength. He found that the presence of clay effects a marked decrease in the permeability of the concrete, and that it slightly decreases the density of concrete containing 10 per cent of cement and slightly increases that containing 11 per cent. He also found that the presence of clay is more advantageous in lean concrete than in richer ones. Unfortunately, no tests were made with a highly plastic clay, such as Devonshire or Dorset ball clay, but it may be considered as proved that the presence of up to 20 per cent of clay in a concrete material can do no possible harm, provided that the clay is of such a kind as to be softened by water and that it is not excessively plastic.

The effect of loam on mixtures of sand and cement is also shown in Table VI., due to R. S. Greenman.

TABLE VI.—EFFECT OF LOAM ON CONCRETE

Per cent of Loam.	Number of Sands tested.*	Average per cent Loam.	Tensile Strength.			
			Natural Sand.		Washed Sand.	
			7 Days.	28 Days.	7 Days.	28 Days.
0-2	7	1.0	128	254	148	261
2.5-3.5	6	3.0	181	273	178	271
5.0-6.0	5	5.6	222	324	205	310

* All the sands contained approximately the same percentage of voids.

The presence of *silt* in concrete is not so harmful as the presence

of clay, yet, although it does not reduce the strength, it tends to rise to the surface of the concrete and cause dusting or scaling.

Micaceous matter in sand for making concrete is also detrimental, as the strength of the concrete is lowered on account of the thin flat plates of mica, tending to cause lamination and flaking.

According to M. Feret, less than 2 per cent of mica has little effect on the tensile strength of concrete, but the compressive strength is appreciably affected. This was confirmed by W. Willis, who found that mica increases the percentage of voids in a sand, 20 per cent increasing the voids from 37 to 67 per cent. The tensile strength of a mixture of 1 part of cement with 3 parts of micaceous sand was reduced as shown in Table VII.

TABLE VII.—EFFECT OF MICA ON STRENGTH OF CONCRETE

Per cent of Mica present.	Tensile Strength in lb. per sq. in.		
	After 7 Days.	After 28 Days.	After 3 Months.
..	180	268	290
2½	140	178	245
7½	95	165	209
5	110	140	180
10-12½	70	120	163
15	62	90	142
20	40	65	105

Felspar should not be present to any great extent as it tends to disintegrate and so weaken the concrete.

The presence of soft and easily decomposable minerals in concrete sands is also undesirable as they reduce the durability of the concrete.

Alumina in sands used for marine concrete should not exceed 6 per cent, though if the alumina is replaced by iron oxide a very satisfactory material is obtained with a high resistance to corrosion.

Iron pyrites should not be present in sands for use in concrete, as it is readily oxidised in the presence of water, thus forming sulphuric acid which attacks the cement.

Lime in an unslaked form should never be present in a sand for use in concrete, as it may, later, expand and cause trouble. According to Sabin, the presence of 2 per cent of ground quicklime in a concrete severely reduces its strength. Properly slaked lime is less harmful, and may even be desirable, in a lean concrete as it increases the mobility of the mass and ensures a better adhesion of the concrete to the reinforcement. M. Feret has found that with St. Malo sand the maximum strength was developed when 4.5 per cent by weight of hydrated lime was present in a mixture of 1 part of cement with 4 parts of sand and lime. In mixtures containing more cement or more lime the strength was lowered.

This is confirmed by the result of experiments made by Sabin and shown in Table VIII.

TABLE VIII.—EFFECT OF LIME ON CONCRETE

Proportions of Cement plus Lime to Sand by Weight.	Proportions of Cement to Sand by Weight.	Cement.	Lime.*	Sand.	Average Tensile Strength.	
					At 28 Days, lb. per sq. in.	At 3 Months, lb. per sq. in.
1 : 3	1 : 3	200	0	600	201	236
1 : 2½	1 : 3	200	20	600	242	265
1 : 3	1 : 3½	180	20	600	238	264
1 : 3	1 : 4	150	50	600	168	171
1 : 3	1 : 6	100	100	600	57	70

* The weight of lime paste was 2.7 times the weights shown in this column.

The beneficial effect of small proportions of fully slaked or hydrated lime and the harmful effect of larger proportions on the strength of concrete may be accepted as established.

Moisture.—The presence of moisture in sands has a very important influence on the percentage of voids, as will be seen from Table LVIII. in Vol. I. p. 264. It also determines the extent to which a sand can be compacted.

The shape of the sand grains is somewhat important, as if they are too smooth and rounded or too flaky, the resulting concrete will be weak. The best-shaped grains are those which are almost spherical (I. 218) yet have moderately sharp angles; such grains are known as sub-angular to distinguish them from the sharply angular, as well as from the rounded grains. According to Feret, the importance of having angular grains is often exaggerated, his experiments having shown that there is little difference between rounded and angular sand, the strength of the concretes being practically the same with each. Any small differences observed are rather in favour of the rounded grains, and the latter certainly facilitate the mixing, tamping, etc., of the concrete as compared with angular ones, as there is less frictional resistance of the particles and the rounded grains tend to roll more easily into the vacant spaces. Angular grains also present a larger surface, and therefore require a slightly larger quantity of binding material, this being more noticeable in weak mixtures containing more than 3 parts of sand to 1 part of cement. Rounded grains also give a rather denser concrete than sub-rounded grains, since spheres when packed give the minimum proportion of voids. Theoretically, when one sphere rests upon another one, the percentage of voids is 47.6; when each sphere rests on three others there is 25.95 per cent of voids. It is impossible to attain these theoretical figures in actual practice even when using the finest sand. H. C. Sorby found that he could not obtain a closer packing than 34 per cent of voids, even after violent tamping and shaking.

Some users have found that a mixture of fine sharp and coarse smooth sand is better than a sand composed entirely of smooth grains.

Where concrete is to be used by pouring or in a cement gun, angular grains are sometimes preferable, as they appear to produce a concrete of greater density than do rounded grains.

Flat grains, such as occur in micaceous sands and rocks, should not be employed, as they tend to lie in one plane and so reduce the strength of the concrete and increase the tendency to lamination.

The size of the sand grains is the principal factor in determining the value of a sand for concrete, as the grading of the sand affects the strength of the final mixture much more than the shape or chemical composition of the grains. As a general rule the sand should be fairly coarse; a large proportion of very fine grains is undesirable as they tend to produce a weak mass. Moreover, the finest particles usually include all the clay and much of the organic matter, both of which are objectionable, and also the greater part of the heavy minerals. Hence, the removal of the smallest particles from a sand affords a simple and ready means of increasing its purity and usefulness. Moreover, on account of their small size, the finest particles tend to introduce more air into concrete. They have also a larger surface area and, consequently, require a larger proportion of cement to coat each grain properly. In extreme cases, a fine sand requires nearly double the normal amount of cement to give a concrete of equal strength. Fine sands also require more water than coarse ones to make an equally smooth paste, and this results in the concrete being more porous unless the workmen are very thoroughly supervised and compelled to avoid the use of an excess of water. Apart from this, however, the presence of apparently inert silica flour or "dust" appears to be objectionable. This is shown by the fact that the presence in a sand of 10 per cent or more of material which will pass through a 50-mesh sieve effects a considerable reduction in the final strength of the concrete. The smallest grains tend to form a coating over the coarser material and prevent the cement from coming into contact with it, so that unless the mixing is extremely thorough, more so than is likely to be attained in actual practice, the mass will be weak, and even when the most thorough mixing is possible, the strength is appreciably reduced. This is confirmed by the results of some tests made by D. Kirkaldy & Son, issued by the Concrete Institute (now the Institution of Structural Engineers), in which the sand consisted of porphyritic granite and blue whinstone, crushed so as to pass through a 30-mesh sieve, and including all the dust. It was compared with a similar mixture of standard sand (I. 162) and cement, the results being as shown in Table IX.

TABLE IX.—EFFECT OF DUST ON CONCRETE

	Tensile Strength, lb. per sq. in.	Crushing Strength, lb. per sq. in.
Standard sand and cement—		
After 7 days . . . . .	..	182.2
After 28 days	2789	234.6
Granite and whinstone crushings and cement—		
After 7 days . . . . .	..	58.2
After 28 days	606	104

D. A. Abrams found that 1 per cent of fine powder ("dust") of the following materials reduces the strength at twenty-eight days of a 1:4 concrete by the percentage indicated: Brick 0.08, Clay 0.22, Kaolin 0.47, Whiting 0.24, Sand 0.37, Natural cement 0.38, Limestone 0.39, Hydrated lime 0.56, Lava 0.40, Tufa 0.51, Fluorspar 0.43, Kieselguhr 0.48, Ironite 0.60, Yellow ochre 0.68, Mica 1.10, Pitch 1.50, Gypsum 4.00. He also found that the effect of fine materials in reducing the strength of concrete was much more pronounced in rich mixtures than in weak ones, mixtures such as 1:9 to 1:6 being little affected or made slightly stronger with various proportions up to 50 per cent of the fine material.

A contrary opinion as to the effect of "dust" and other very fine particles in sand is held by some investigators and users. Thus, H. L. Rogers considers that the removal of the fine material, as suggested by the Concrete Institute, is not good practice, because, whilst it admittedly gives a greater surface area and contains a larger quantity of air which is difficult to displace, yet it has the advantage of fully filling up some of the spaces between the grains of medium sand which is often badly graded; for this reason the presence of dust or flour sand tends to save cement and make the concrete more impervious to water. Sometimes the gain in imperviousness is more important than the loss in strength. On the other hand, it is specially important that very fine sand should not be used in concrete which is subjected to the action of sea water, as this appears to be a common cause of failure in such concrete.

The men engaged in the production and placing of concrete prefer a material containing fine sand because it is more easily worked than one in which only coarse sand is used. This advantage is, however, generally far outweighed by the disadvantages.

The best relation of the sizes of the sand and coarse aggregate is not fully understood, but a coarser sand is usually required for a very coarse aggregate than is desirable for an aggregate composed of smaller particles.

Partly as a result of conflicting evidence and opinions, and partly with a desire for cheapness, the limits of size of grains in

the sands used by different builders and contractors are very varied.

The British Standard Specification for Portland cement directs that the sand used for testing must pass wholly through a 20-mesh sieve and be retained on a 30-mesh sieve, but in the preparation of concrete on a large scale such a narrow limit of size would be impracticable. Sand which conforms strictly to the Standard sand used in testing cements does not produce so strong a concrete as that containing a wide range of particles. For this reason it is better to regard the upper or coarser limit for sand used in concrete as determined by a 20-mesh sieve and the lower or finer limit by a 50-mesh sieve. The Standing Committee of the Concrete Institute have fixed the upper limit of sand as that which passes through a $\frac{1}{4}$ -in. by $\frac{1}{8}$ -in. sieve and the lower limit as that which is retained on a $\frac{1}{16}$ -in. by $\frac{1}{32}$ -in. aperture. Taylor and Thompson, whose recommendations are largely followed in the United States, adopt the same limits, but they also specify that "fine aggregates shall be of such quality that mortar composed of 1 part of Portland cement and 3 parts of fine aggregate by weight, when made into briquettes or into prisms or cylinders, will show a tensile strength at an age of not less than seven days at least equal to the strength of 1 : 3 mortar of the same consistency made with the same cement and Standard Ottawa sand. If the aggregate be of poorer quality the proportion of cement shall be increased in the mortar in order to secure the desired strength. If the strength developed by the aggregate in the 1 : 3 mortar is less than 70 per cent of the strength of the Ottawa sand mortar the material shall be rejected. To avoid the removal of any coating on the grains, which may affect the strength, bank sands shall not be dried before being made into mortar, but shall contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting the weight. From 10 to 40 per cent more water may be required in mixing bank or artificial sands than for Standard Ottawa sand to produce the same consistency." The Committee of the Royal Institute of British Architects specifies a sand composed of hard grains of various sizes up to those which will pass a $\frac{1}{4}$ -in. square mesh, but of which at least 75 per cent should pass an $\frac{1}{8}$ -in. square mesh. Fine sand alone should not be used, as it is unsuitable.

The imposition of a strength test is very desirable in the case of important concrete work, especially where the mass is comparatively thin, as for such work the sand used must not merely be clean and well graded; the person responsible for the constructional work should satisfy himself that, when mixed with cement, the sand yields a product having at least the same strength as is produced by standard sand in laboratory tests. With a well-graded sand containing a sufficient proportion of moderately fine grains the strength will be greater than will that of "Standard Sand."

Another useful specification which applies equally to the sand and coarser aggregate will be found on p. 37.

Not only should the sand be within the size limits mentioned above, but it should also consist of grains of various sizes within these limits, so that the sand, when shaken and tamped lightly, will produce a mass with the minimum proportion of voids. If all the particles are of the same size this will not be the case, and such a sand would produce a weak concrete on account of the greater proportion of voids present unless a larger proportion of cement is used, and even then some of the interstices tend to remain unfilled and so reduce the strength of the concrete. Fig. 3 shows a diagram of a number of particles of uniform size. It will be seen that the voids between them are quite large. Fig. 4 shows the

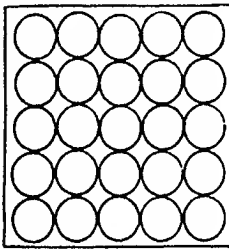


FIG. 3.
Sand-particles of one grade.

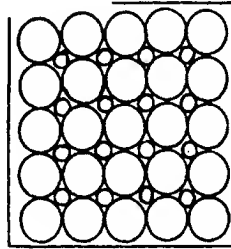


FIG. 4.
Graded sand (with two grades).

proportion of voids considerably reduced by the addition of a number of smaller grains which fill up some of the spaces between the large grains. Still less space would be left if further groups, each containing successively smaller sizes of grains, were added. From this it will be clear that the sand must be very carefully graded and composed of particles of a sufficient number of different sizes, otherwise it will produce either a weak concrete or will require a very large proportion of cement. As the cost of the additional cement is far greater than the cost of grading the sand, a careful grading of the material effects a considerable saving.

The effect of grading is well shown by a comparison of the tensile and compressive strengths of mixtures of sand and Portland cement. According to M. Feret, their relationship is shown by the following formula :

$$P = K \left(\frac{C}{1-S} \right)^2,$$

where P represents the compressive strength of the mixture in lb. per sq. in., C represents the volume of cement in the mixture, S is the volume of sand in the mixture, and K is a constant depending

on the nature of the sand and cement used. M. Feret tested mixtures of three grades of sand—(a) 5-15 mesh, (b) 15-46 mesh, (c) less than 46-mesh—and found that the strongest mixture consisted of 2 parts of coarse grains to 1 part of fine grains and cement. M. Feret has plotted his results on a triaxial diagram (I. 214); this affords a simple means of showing the volume of sands of deficient fineness, the compositions having the same volume being joined up by contour lines.

It is, however, impossible to compare sands entirely by a comparison of the percentage of voids, as the proportion of moisture present in each sand varies and alters the results (I. 264).

Table X., due to Taylor and Thompson, shows the marked effect of variously graded sands on the compressive strength of 1 : 3 mixture of cement and sand.

TABLE X.—EFFECT OF GRADING SAND

Sand.	4-in. Mesh.	3-in. Mesh.	20-Mesh.	50-Mesh.	200-Mesh.	Per cent Voids.	Compressive Strength 7 Days, lb. per sq. in.
1	100	84	62	28	3	31.1	715
2	100	100	84	77	6	38	405
3	100	100	92	84	27	40	330

The effect of grading, as shown by the proportion of voids in the sand, is also shown in Table XI., due to R. S. Greenman.

TABLE XI.—EFFECT OF VOIDS IN SAND

Per cent of Voids in washed Sand.	Number of Sands tested.	Per cent through 100 sieve.	Average per cent Voids.	Tensile Strength.*	
				7 Days.	28 Days.
25-30	5	2.8	27.8	192	310
30-35	17	6.4	33.0	164	256
35-40	11	6.7	37.8	140	220

* Results taken only on washed samples so that the effect of loam would be nil.

The testing of various mixtures is the only really definite method which can be employed and should never be omitted in important work.

Conversely, the effect of grading on the percentage of voids is shown in Table XII., by R. S. Greenman.

TABLE XII.—EFFECT OF GRADING ON VOIDS

	Percentage of Sand passing Sieves Nos.												Per cent of Voids.
	2.	4.	6.	10.	20.	30.	40.	60.	74.	100.	140.	200.	
A	100	99	98	89	69	47	29	14	8	3.8	2.3	1.6	32
B	100	99	98	96	87	72	56	31	17	5.8	2.6	1.6	33.4
C	100	100	99	98	95	79	60	38	20	7.5	3.6	1.6	36.6

The proportion of voids in various sands is shown in Table XIII., compiled by the Cement Marketing Co., Ltd.

TABLE XIII.—PROPORTION OF VOIDS IN SANDS

	Solids per cent.	Voids per cent.
Moist sand under 18-mesh	57	43
„ over 18-mesh	65	35
„ mixed	62	38
Dry sand mixed	70	30
Stone screenings and dust	58	42

According to Fuller and Thompson, in an ideal sand the proportion of grains of various sizes and their diameters, when plotted on a graph, should be in the form of an ellipse, to which the graph of the coarse material (which should be a straight line) should form a tangent (Fig. 12, Vol. I. p. 216). Such an ideal graph may be constructed from the information in Table XIV.

TABLE XIV.

	Intersecting of Tangent with Vertical at Zero Diameter.	Height of Tangent Point.	Axes of Ellipses.	
			a.	b and c.
Crushed stone and sand	28.5	37.7	0.150 D	37.4
Gravel and stone	26.0	33.4	0.164 D	35.6
Crushed stone and screenings	29.0	36.1	0.147 D	37.8

In order to construct the ideal graph of the constituents of a concrete, the value given for *a* is multiplied by the maximum size of the coarsest particles and the resultant figure marked off on the horizontal scale of sizes of particles. A vertical line through this

point forms the axis of the ellipse. The value b is found from the table and the length of the vertical axis is laid with its centre 7 per cent above the horizontal line of the graph. The ellipse is then completed and the straight-line graph of the aggregate drawn from the point of intersection of the 100-per-cent line and the line denoting the largest-sized particles to a point representing the point of intersection of the tangent with the vertical at zero diameter, the value for this being found from the table. This line should form a tangent to the ellipse. Where an artificial mixture cannot be prepared to coincide exactly with the ideal curve it should preferably intersect on the 40-per-cent line.

Another very ingenious method of comparing concrete sands, devised by L. N. Edwards, bases the comparison on the surface area of the particles and is similar in principle to the surface factor method (1. 211). The number of particles of sand per gram for each size of particle is found by counting and by finding the weight per gram of the material, its specific gravity, volume per gram and average diameter of the grains; the surface area per gram can then be calculated. From this, the average surface area of a sand can be found by multiplying the percentage of grains of each size by the corresponding surface area per gram and dividing the total of these figures by 100. As a result of his work along these lines, L. N. Edwards has suggested grading concrete sands as shown in Table XV.

TABLE XV. - PROPOSED GRADING SCALE

Size of Particles.	Percentage.
Over $\frac{1}{4}$ -in. mesh	Nil
10-mesh	Not more than 80 per cent
20 "	" 55 "
50 "	" 15 "
100 "	" 5 "

The Tests Committee of the Concrete Institute have suggested that "sand" shall be divided by sifting, into the following grades and the percentage of voids ascertained in (a) the whole and (b) each separate grade:

To pass by an aperture of	To be retained by an aperture of
$\frac{1}{4}$ in. by $\frac{1}{4}$ in.	$\frac{1}{8}$ in. " $\frac{1}{8}$ in.
$\frac{1}{8}$ in. " $\frac{1}{8}$ in.	$\frac{1}{16}$ in. " $\frac{1}{16}$ in.
$\frac{1}{16}$ in. " $\frac{1}{16}$ in.	$\frac{1}{32}$ in. " $\frac{1}{32}$ in.
$\frac{1}{32}$ in. " $\frac{1}{32}$ in.	" $\frac{1}{50}$ in. " $\frac{1}{50}$ in.

The proportion of each grade to the whole and the specific gravity of the sand should also be ascertained. No definite proportions have been fixed.

The effect of the size and grading of the sand on the porosity

of permeability of concrete is shown in Table XVI., due to S. P. Thompson.

TABLE XVI.—EFFECT OF GRADING ON THE POROSITY OF THE CONCRETE WITH COARSE AND FINE SAND

Proportions 1 : 3 : 6, by volume, or 1 : 2.8 : 5.7 by weight, age 32 days.

Character of Sand.	Density.	Water passing in Grams per Minute.
1. All coarse	0.853	145.1
2. 5/6 coarse, 1/6 fine	0.846	10.4
3. 2/3 coarse, 1/3 fine	0.843	43.0
4. All fine	0.813	30.2

The grading of the sands used by Thompson is shown in Table XVII.

TABLE XVII.—ANALYSES OF NATURAL SAND AND SCREEN GRAVEL USED IN TESTS

Sieve.	Coarse Sand, per cent.	Fine Sand, per cent.	Screened Gravel, per cent.
1 in. . . . .	..	..	100
$\frac{1}{2}$ in. . . . .	..	..	50
$\frac{1}{4}$ in.	100	..	0
No. 5	88	..	..
No. 12	77	100	..
No. 40	32	96	..
No. 200	3	27	..

A sand of a specified grade may sometimes be best obtained by mixing two or more different sands or grades together.

It must always be remembered in grading sands for concrete, that a sand should not be too rich in the finest particles (see p. 32).

The hardness of the particles of sand used in concrete is less important than that of the coarse aggregate, nor does the strength of the grains seriously affect that of the finished concrete, provided they are able to withstand weathering. Sands which are readily decomposed on exposure should, obviously, not be used for concrete.

The specific gravity of a sand suitable for concrete should not be less than 2.45.

The volume-weight of a sand (I. 222) is a fairly good indication of the proportion of voids present (I. 222). Thus, a fine sharp sand weighs about 92 lb. per cu. ft., a coarse sharp sand weighs about 90 lb. per cu. ft., whilst a mixture of equal parts of the two weighs about 102 lb. per cu. ft., as the proportion of voids is greatly reduced. Sands composed of rounded grains have a larger proportion of voids and are consequently lighter than more angular ones. Thus, a fine smooth sand weighs about 86 lb. per cu. ft.,

a coarse smooth sand 84 lb. per cu. ft., and a mixture of equal parts of coarse and fine about 94 lb. per cu. ft.

Preparation of Sands for use in Concrete Making.—Where possible, it is both better and cheaper to use a sand without any preparation, but few sands are suitable without some treatment; this should, however, be as little as possible, otherwise the cost of preparation may be prohibitive. Quite apart from the cost, unnecessary treatment of the sand is objectionable, as it tends to separate one or more grades and to cause an indefinite amount of segregation, with the result that the uniformity of texture possessed by the material is to some extent destroyed. For this reason, if a sand has been subjected to any considerable amount of treatment, it should be thoroughly mixed before it is used for concrete. The mixing which the various materials forming the concrete undergo is not sufficiently thorough for some treated or "compounded" sands.

Crushing.—Where the sand is in the form of a rock it must be crushed or ground, as described in Vol. I. p. 346, to reduce it to grains of suitable size. The cost of grinding is sometimes very high.

Washing.—Sands for making concrete must be washed if they are not sufficiently clean or if they contain too large a proportion of fine material. Various methods of washing may be employed, according to the amount of sand to be treated. Where only a small quantity of concrete is made, a simple trough washer (I. 385) is quite sufficient, but for larger quantities of sand a rotary sand washer (I. 389) or one of the various machines mentioned in Vol. I. pp. 385-400 should be employed.

Grading.—In order to produce good concrete the sand should consist of particles of various sizes so as to contain only a small proportion of voids. The percentage of voids most suitable for concrete sands is between 23 and 40 per cent. If a sand naturally contains the various sizes of grains in suitable proportions, or if a mixed sand is used which conforms to these requirements, it is clearly unnecessary to sift or grade the sand, and many builders and contractors do not even trouble to test the sand in order to know whether it requires grading. For rough mass concrete, it is often sufficient to use the sand "as it comes," but for reinforced concrete and for special moulded work a careful grading is desirable. Where it is necessary one of the appliances mentioned in Vol. I. pp. 441-468 should be employed. For large quantities of sand a series of rotary screens (I. 456) is very satisfactory for separating the sand into various grades. The most suitable grades are then mixed in the right proportions, other sands being added if required. The grades and proportions must largely depend on the particular purpose for which the concrete is required, but they may be judged in general terms from the information given on pp. 32-39.

Testing Sand for Concrete.—The principal tests to be applied to the sand are given below. It is most important that all sand

should be tested before use in concrete, as otherwise inexplicable variations in the quality of the concrete may occur.

1. Microscopical examination, including a report on the shape and sizes of the particles (I. 241).

2. A grading or screening test showing the proportion of sand in each of the principal sizes of grains, or plotted on a graph-sheet as in Fig. 12 (Vol. I. p. 216).

3. A cleanness test, such as that devised by Abrams and Harder and described in Vol. I. p. 244, is specially suitable for testing concrete sands, and has already been largely adopted in America on account of its simplicity and the fact that no expensive apparatus is necessary.

4. A determination of the proportion of voids, determined as described in Vol. I. p. 261.

5. The weight per cu. ft. or the equivalent volume-weight. This is determined as described in Vol. I. p. 259.

6. The tensile strength of a mixture of standard Portland cement and the sand to be tested in various proportions. In American specifications the tensile strength of a 1 : 3 mixture of cement and the sand to be tested should be at least 75 per cent of the strength of a similar mixture of cement and a standard sand. In this country, that portion of Leighton Buzzard sand is taken as standard which passes completely through a 20-mesh sieve but is retained on a 30-mesh sieve.

In special cases a chemical analysis or other physical or chemical tests may be required, but this is unusual.

Further information on concrete will be found in the author's *Cement, Concrete, and Bricks* (Constable), and in numerous other works dealing with concrete.



CHAPTER III

THE USE OF SANDS IN CEMENTS AND MORTARS

CEMENTS and mortars comprise a class of substances which, when mixed with water, are more or less plastic and consist of a binding material with or without an inert material or filler. The terms "cement" and "mortar" are, however, so loosely applied in industry that it is, in some cases, very difficult to discriminate between them. Some "cements," for example, consist wholly of a binding agent, whilst others contain a considerable proportion of inert filler. Plasters are sometimes so like mortars that they can scarcely be distinguished, and mortars vary so greatly in their properties that some of them might conceivably be termed cements or plasters. For the present purpose, however, it is convenient to regard Portland cement as typical of the cements used in connection with sand, ordinary building mortar as a typical "mortar," and the plasters as typified by plaster of Paris. Such materials are used for fastening together stones and bricks, chiefly in the construction of buildings, bridges, etc., or for covering walls and ceilings.

Cements used in connection with sand may be divided into the eight following groups:

Various mixtures of *Portland cement and sand*, which are more fully described under "cement mortars" (p.43), though a mixture of 1 part of Portland cement with 1, 2, or 3 parts of fine sand well ground together is sometimes sold as *sand cement*. The statement is sometimes made that this sand cement is equally as strong as Portland cement and much cheaper; such a statement is only true provided the cement is to be used neat.

The effect of adding fine sand to sand cement is shown in Table XVIII., due to Smith.

Other cements which contain sand or its equivalent as an essential ingredient include—

Borax cements in which borax is mixed with fine sand or other inert material.

Cement grout is a watery mixture of Portland cement and sand.

Dental cements, which consist of fine sand, powdered glass, or other inert material mixed with zinc oxide, borax, and zinc chloride.

TABLE XVIII.—TENSILE AND COMPRESSIVE STRENGTH OF SAND CEMENTS

Brand	A.	B.	C.
Sand cement composed of	1 cement 1 sand	1 cement 1 sand	1 cement 6 sand
Fineness passing 100 mesh	99.8	99.4	99.7
„ 120 mesh . . . . .	..	99.3	98.4
„ 180 mesh	99.3	..	..
Neat sand cement: tension 1 week	332	..	..
„ 4 weeks	475	..	..
„ 4 months . . . . .	..	810	340
„ 6 months . . . . .	..	780	540
„ compression 4 weeks	3837	..	..
Sand 2, sand cement 1: tension 1 week . . . . .	..	..	300
„ 2 weeks . . . . .	..	..	379
„ compression 1 week . . . . .	..	..	2800
Sand cement 1, sand 2: tension 1 week . . . . .	..	..	184
„ 2 weeks . . . . .	..	..	215
„ compression 1 week . . . . .	..	..	1225
Sand cement 1, sand 3: tension 1 week	135	189	..
„ 2 weeks . . . . .	..	201	..
„ 4 weeks	141	..	..
„ 2 months	135	..	..
„ compression 1 week	470	900	..
„ 4 weeks	687	..	..

The sand, which should be white and very fine, acts merely as a filler.

Kieselguhr cement, which consists of a mixture of kieselguhr and molten paraffin wax, which is used for cementing acid-proof bricks.

Lead cements, which consist of a mixture of sand or other inert material, with white lead or litharge, lime, or plaster of Paris, and linseed oil. The sand merely acts as a diluent or filler, enabling less of the white lead to be used than would otherwise be the case.

Oxychloride cements, which consist of mixtures of sand or other inert material and magnesium oxychloride, produced by mixing magnesia and syrupy magnesium chloride. The sand is in this case merely a filler, which is used on account of its cheapness. The finer and whiter the sand the better will it serve its purpose.

Refractory cements, which are used for lining furnaces subjected to a high temperature. They are described in Chapter VII.

Mixtures of cement and sand which are used for coating brick-work are classed as plasters to avoid confusion.

Mortars may be divided into the following classes, depending on the materials used in their preparation:

Lime mortars, which consist of a suitable mixture of lime and sand in proportions usually varying from 1:2 to 1:4.

Lime-cement mortar, which consists of a mixture of lime,

Portland cement, and sand, the lime being added chiefly for the purpose of making the mortar more plastic and easier to use.

Clay mortars, which usually consist of a mixture of fireclay and sand or brick-dust; they are chiefly used for laying brickwork in furnaces and kilns (see Chapter VII.), but are occasionally employed where brickwork is of a temporary nature, as in exhibitions, etc.

Trass mortars, which contain, in addition to lime and sand, a proportion of trass. They may be regarded as lime mortars in which trass replaces part of the sand (l. 165). The proportions are usually from lime 1, trass $1\frac{1}{4}$, sand $1\frac{1}{2}$, to lime 1, trass $1\frac{1}{4}$, sand 3-4. In some cases lime and trass are used without the addition of sand in the proportions of 1 : $1\frac{1}{4}$ to 1 : $1\frac{1}{2}$. Where such mixtures are employed satisfactorily it will generally be found that the lime and trass or pozzuolana are impure and contain a sufficient quantity of sand or other inert material to render further additions unnecessary. Where the lime is pure and the trass is finely ground the addition of sand is generally necessary. In Holland and Belgium, mixtures of sand, trass, and lime are largely used for important work. The best proportions (as suggested above) are those in which there is sufficient trass to combine with the lime to form a calcium silicate analogous to cement, and so form a much stronger material than when the sand is omitted (see p. 25). A mixture of trass and lime, without any sand, is still used to some extent, though it is rather uneconomical, as the cost is much greater than when sand is added, and the excess of trass over and above that required to combine with the lime is quite inert and may be satisfactorily replaced by sand. Calcined clay may replace the trass.

Pozzuolana mortars are the same as trass mortars, except that pozzuolana replaces the trass.

The chief purposes served by the sand used in mortars are—(i.) to act as a diluent and so prevent it from cracking, and (ii.) to bring the irregular surfaces of the bricks, stones, or other articles which are to be united into contact with the binding agent and indirectly with each other. For instance, if an attempt were to be made to unite two bricks by means of a plastic clay, it would usually be necessary to have a much larger layer of the clay between the bricks, as otherwise they could not be properly united, as their surfaces are too irregular and the clay, as it dried, would shrink and crack. This shrinkage, with eventual cracking of the material, if it is sufficiently free to do so, is a characteristic of most colloidal gels, including many cements and glues as well as various plastic substances. It is a serious objection to the use of all such materials except in the form of thin films, when the maximum adhesiveness is obtained with a minimum of cracking. As the use of only a single thin film of cement is impracticable in many branches of the building trade (it is, of course, used in carpentry and joinery, where pieces of wood are glued together) the difficulty is overcome by mixing sand with the binding agent in such proportions that

the grains of sand occupy the bulk of the space between the particles to be united and leave only a series of small interstices to be filled with "films" of binding material. Such a use of sand as a "filler" enables the best possible use to be made of the binding agent, such as lime or Portland cement; the sand is, therefore, an essential constituent of the mortar and not merely an adulterant.

Sand in mortar has a further beneficial effect, inasmuch as it regulates the hardening of the cement or mortar. This hardening is due, in the case of cements, to a combination of the cement with water, and in the case of lime mortar, to a combination of the lime with carbon dioxide in the air. The speed of the reaction is the determining factor in the resultant hardness of the mortar. It is most important that the reaction should take place very slowly if a hard mass is to be produced. In the case of mortars containing fat lime and hardening by the absorption of carbon dioxide from the atmosphere by the lime, the pores of the lime are so small that the hardening proceeds very slowly with neat lime, as it is difficult for the carbon dioxide to penetrate into the interior. When sand is added, however, the mass is "opened up" and the pores are enlarged, so that the gas has free access; consequently, sand facilitates the hardening of such mortar. The strength of the mortar depends partly on the proportion of sand present, and this must be suited to the nature of the binding material used. An excess of sand is undesirable in any mortar, as it reduces the cohesion of the particles and so weakens the mortar. The most suitable proportion of sand must be found by trial and adjusted so as to give a mortar which is as hard and as strong as possible.

The effect of the proportion of sand used in cement mortars on the strength of the mortar is shown on pp. 31-39. The corresponding effect of sand on lime mortar is shown in Table XIX., due to Sabin.

TABLE XIX.—EFFECT OF SAND ON FAT LIME IN MORTARS

Parts by Weight.		Kind of Sand.	Age.	Average Tensile Strength, lb. per sq. in.
Lime.	Sand.			
1	3	U.S.A. Standard	28 days	46
1	6	"	"	62
1	8.4	"	"	47
1	11.8	"	"	39
1	17.7	"	"	20
1	6	Screened 20-40 mesh	29 days	51
1	8.8	"	"	64
1	11.8	"	"	56
1	17.7	"	"	43

It will be seen that up to a certain point an increase in the proportion of sand gives a stronger mortar, but if an excess of sand

is used the strength is greatly reduced. In hydraulic limes a certain amount of inert matter occurs in the lime, so that a smaller proportion of sand is required before the mortar is reduced in strength. The effect of sand upon the strength of hydraulic lime is shown in Table XX., due to Grant.

TABLE XX.—STRENGTH OF HYDRAULIC LIME MORTARS

Composition of Mortar.	1 lime : 3 sand.		1 lime : 4 sand.		1 lime : 5 sand.		1 lime : 6 sand.	
	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
Lime A . .	lb. 50	lb. 68	lb. 44	lb. 57	lb. 30	lb. 45	lb. 21	lb. 28
Lime B . .	48	95	49	59	32	47	23	27
Lime C . .	40	81	26	61	21	44	18	34
Average . .	46	81	40	59	28	45	21	30

The dry samples were kept in air one year before testing, whilst the wet samples were kept under water for a corresponding period. Each result is the average strength shown by five tests.

Selenitic limes mixed with sand produce much stronger mortars than ordinary limes, but an increase in the proportion of sand decreases the strength as with ordinary limes, as shown in Tables XXI. and XXII., due to Grant. The wet and dry samples were kept for one year in water and air respectively before testing, the strengths given being the average of five tests on each mixture.

TABLE XXI.—TENSILE STRENGTH OF SELENITIC LIME

		Tensile Strength, lb. per sq. in.							
		1 lime : 3 sand.		1 lime : 4 sand.		1 lime : 5 sand.		1 lime : 6 sand.	
		Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
A.	Gray limo. not selenitic . .	50	68	44	57	30	45	21	28
A1.	Gray lime, selenitic . .	128	141	65	139	55	87	40	65
B.	Lias lime, not selenitic . .	48	95	49	59	32	47	23	27
B1.	Lias lime, selenitic . .	79	131	63	99	44	72	52	80
C.	Selenitic lime . .	123	148	80	129	72	81	58	74
D.	Selenitic lime (Rugby) . .	91	151	59	102	33	77	29	66
E.	Selenitic lime (Aberthaw) . .	128	204	93	147	71	123	..	76

The effect of sand on mortars may also be expressed in terms of adhesiveness; the greater the proportion of sand the less is

TABLE XXII.—COMPRESSIVE STRENGTH OF SELENITIC LIME

		Compressive Strength, lb. per sq. in.		
		1 lime : 6 sand.	1 lime : 8 sand.	1 lime : 10 sand.
A.	Gray lime, not selenitic.	159	72	81
Al.	Gray lime, selenitic .	289	119	127
B.	Lias lime, not selenitic .	178	172	179
Bl.	Lias lime, selenitic . .	268	305	159
C.	Selenitic lime	414	239	210
D.	Selenitic lime (Rugby) .	577	533	329
E.	Selenitic lime (Aberthaw)	530	339	239

the tenacity with which the mortar adheres to the surfaces to be united. The reduction in adhesiveness caused by increasing the proportion of sand used in mortars is shown in Table XXIII., due to Hodgson.

TABLE XXIII. EFFECT OF SAND ON ADHESIVENESS OF MORTAR

Mixture.	Proportions, Lime : Sand.	Force required to break apart two bricks cemented with Lime Mortar after 28 Days.
Fat lime and sand	1 : 3	4 $\frac{1}{2}$ lb. per sq. in.
Lias lime and sand	1 : 3	9 " "
Lias lime and sand	1 : 4	6 $\frac{1}{2}$ " "
Portland cement and sand .	1 : 4	23 " "
Portland cement and sand .	1 : 6	15 $\frac{1}{2}$ " "

Sources of Sand for Cements and Mortars.—Almost any kind of sand can be used satisfactorily if its grains are sufficiently angular and if the sand does not contain too much clayey matter.

Sand from river beds is generally preferred, as it is usually free from clay, though sand from tidal rivers is often objectionable because the grains are too rounded. Where river sand is too costly, pit sand, blown sand, and even rock dust are often used for making mortars. They are inferior to river sand when they contain a comparatively large proportion of matter so fine as to pass a 200-mesh sieve, and this should preferably be removed before the sand is used if sufficient of it is present to prevent the adhesion of the binding material to the sand and impede the hardening of the mortar. It is usually more economical to pay a rather high price to secure a good natural sand than to use a cheaper one which requires washing.

Sand from the seashore is seldom suitable for mortars, as the grains are so smooth and rounded that they do not permit

sufficient adhesion of the cement or lime. The soluble salt present in sea sand is also objectionable (l. 156).

* Quicksand, which consists of highly rounded grains, should never be used for mortar-making, as it tends to settle to the bottom of the mortar after mixing and produces a non-homogeneous mass which is very weak and unsatisfactory.

The sands stated on pp. 23-26 as being suitable for concrete are, without exception, equally suitable for mortar, but, in addition, sands which contain not more than 25 per cent of material passing through a 50-mesh sieve but remaining on an 80-mesh sieve may be used for mortar, especially for structures where a very strong mortar is unnecessary.

Sands for Cements and Mortars.—The best sands for use in cements and mortars are practically the same as for the fine aggregate in concrete. In fact, the fine aggregate and cement in concrete really form a cement mortar, and the reader should refer to pp. 31-40 for further information as to its properties and treatment.

The **chemical composition** of the inert material used for cements and mortars and plasters is not usually of great importance, where an ordinary siliceous sand is used, and in some instances calcareous sands (l. 86) are quite satisfactory. If the physical properties of the sand are suitable, and the proportion of impurities is not excessive, a detailed consideration of the chemical composition is seldom necessary. The possible ingredients (other than quartz) which may require attention include the following:

Colloidal silica is always desirable in a sand to be used for concrete, cement, or mortar, as it forms a calcium silicate and so increases the strength of the mortar. It is, however, very difficult to control or increase the proportion of colloidal matter present, and in most cases no attention is paid to it. Where rocks are crushed to form sand, it is desirable to select a sandstone which contains colloidal silica as a rock cement.

The presence of *soluble salts* is very undesirable in sands used for making mortar, on account of the efflorescence or scum caused on drying. The water containing the salts travels to the surface during the drying of the mortar and is evaporated, leaving a layer of white furry matter on the surface. Much of the efflorescence found on brick walls is not due to soluble salts in the bricks, as is often suggested, but to those in the mortar, which have been absorbed by the bricks and have afterwards risen to their surface.

In countries where cement mortar has to be used during periods of intense frost, common salt is sometimes added to lower the freezing-point of the water until the mortar has had time to harden and so prevent disintegration of the joints in the structural work. This enables the building to be continued under conditions where it would otherwise be impossible, but it is not desirable under ordinary conditions.

Clayey matter, silt, etc., are objectionable in cements and mortars

as they tend to coat the grains of sand and prevent the lime or cement from coming into sufficiently close contact with them, thus retarding the setting and hardening of the mass. If the sand contains less than 5 per cent of material passing through a 200-mesh sieve, this proportion is not very serious, but if an appreciably larger quantity is present, the sand should be washed prior to use. Some authorities claim that a little clay is useful in mortar, just as it sometimes is useful in concrete (see p. 27), whilst W. T. Dibden stated that clay is objectionable in mortars made with white chalk or greystone lime, but that it markedly improves mortars made with blue lias lime. It is difficult to understand how this can be the case with *raw* clay; if the clay had been calcined its advantage is obvious, as it then forms an artificial trass (I. 165). W. T. Dibden has found that the mortar used in constructing London Wall contained 19.5 per cent of clean, ferruginous clay; samples of mortar from Allington Castle, built in the early thirteenth century, contain 8.6, 3.66, and 4 per cent of ferruginous clay. This great variation in the proportion of clay suggests that its presence was accidental rather than intentional.

In sands which contain little or no fine material a small proportion of lean clay, or preferably silt, is sometimes an advantage, as it acts as a fine sand and fills interstices. Thus, a mixture of 1 volume of greystone lime and 5 volumes of Standard sand tested by W. T. Dibden had a crushing strength of 42 lb. per sq. in., whilst with $7\frac{1}{2}$ per cent of clay it was increased to 183 lb. per sq. in., and with 2 volumes of sand and 10 per cent of clay the crushing strength was 223 lb. per sq. in. For further information on the action of clay in mixtures of sand and cement see pp. 27-30.

Mica and *felspar* should not be present in sands used for mortar, the former being specially objectionable (p. 30).

Trass (I. 165) or *pozzuolana* (I. 136) or *lightly calcined clay* (I. 136), is a very useful addition to mortars in place of part of the sand, as it combines with free lime and water, and the compound, having hydraulic qualities, begins to harden almost immediately and produces a harder and stronger mortar. The addition of one of these materials has a further advantage, as in plain mortar the hardening only occurs at the surface, whereas when a small proportion of pozzuolana, trass, or calcined clay is present, the mortar hardens throughout. As is well known, the hardening of ordinary mortar is due to the reaction of carbon dioxide on the lime, and if the mortar is dense it is very difficult for the action to occur in the centre of the mortar. The trass, pozzuolana, or calcined clay, however, hardens independently of the air, as its hardening depends on a chemical reaction between it and the lime and water present, hard durable silicates being formed, whereas ordinary lime mortar chiefly hardens by the formation of carbonates. By this means, the hardening of mortar is rendered partly independent of the air, though the trass or its equivalent hardens more slowly than the surface of ordinary mortar. When mixing

mortars, the trass, pozzuolana, or calcined clay should be added to the dry cement or lime, mixed thoroughly in a dry state and this mixture added to the sand, the water being added last.

For further details on the purpose and use of trass, pozzuolana, and calcined clay in mortar, see Vol. I. p. 136.

Ground cinders are sometimes employed as a cheap substitute for sand, but they have the great disadvantage of introducing soluble salts into the mortar; these, on drying, appear as seum on the surface of the work and render it unsightly (I. 193). The lime and soluble salts in ashes make them undesirable in cement mortars, as they affect the setting time of the cement and also alter the proportion of binder to inert material, so that the properties of the mixture are not under proper control. The lime may also cause flaking after the cement has begun to set.

Brick-dust, when added in small proportion to a lime mortar, aids the hardening and tends to prevent the disintegration of the material. Its action is similar to that of trass (I. 165). A good mixture is 1 part of brick-dust, 2 parts of sand, 1 part of lime. The dust should be obtained from under-burned bricks.

Stone-dust and *fine screenings* may be used to replace part of the sand in mortar and may be quite satisfactory (see also p. 24).

They are specially useful for mortars made with Portland cement and by their use the strength of the mortar may sometimes be increased by as much as 55 per cent.

Marble-dust is sometimes used to replace part of the sand in making very fine joints.

The *shape* of the particles of sand in cements and mortars is not so important as is sometimes supposed. It is commonly stated that the grains should be sharp and angular, but this must not be taken as a hard-and-fast rule, as other considerations may rightly influence the choice of a sand. Thus, a sand composed of somewhat rounded, but very clean grains, may be preferable to one which has more angular grains but contains much "dirt" or clayey matter. Mortars made with sharp sand have a greater tensile strength than those made with rounded grains, but many of the latter have a greater compressive strength if the grains are not too smooth (I. 225).

For use in mortar, the grains of sand should preferably have a roughened surface, as this aids the adhesion of the cement or lime and it is most essential that the mortar should form a well-bonded, homogeneous mass, or it will crumble to dust or be washed out of the joints by the weather.

The *size* of the particles of sand or other inert matter in a mortar should depend on the purpose for which the mortar is to be used, but in most cases the grains should be fairly coarse. Sands composed chiefly of grains smaller than 60-mesh should not be used for mortars, as such fine sands form "dry" mortars which do not adhere well to the stones or bricks they are intended to unite. This is particularly the case with fine sands containing

soft limestone and shells. Where the joints are to be very thin and close, however, a finer sand may be used than is desirable for wider joints, and in the best ashlar masonry the finest sharp grained sand obtainable should be used, as there are only very small cavities to fill up and the very thinnest possible joints are required. In relatively large masses of mortar, such as may occur in rubble work, small gravel or crushed stone should be used in addition to the sand, so as to break up the large spaces which would otherwise have to be filled with mortar.

A coarse sand has the advantage of allowing the carbon dioxide in the atmosphere to penetrate fairly readily into the interior of the mortar and so facilitate the hardening process.

The effect of using grains of sands of various sizes is shown in Table XXIV. by Sabin.

TABLE XXIV. — EFFECT OF GRAIN-SIZE ON THE STRENGTH OF LIME MORTARS

Parts by Weight.		Kind of Sand.	Size of Grains.	Age of Mortar.	Average Tensile Strength, lb. per sq. in.
Lime.	Sand.				
1	8.8	Natural	10-mesh	3 months	67
1	8.8	Standard	20-30	..	52
1	8.8	Screened	20-40	..	71
1	6	Standard	20-30	..	47
1	6	Screened	20-40	..	56
1	11.8	Standard	20-30	..	47
1	11.8	Screened	20-40	..	55
1	17.7	Standard	20-30	..	36
1	17.7	Screened	20-40	..	39

It will be seen from Table XIX. that the grading has an important effect on the strength of the mortar. The sands which are regarded as "standard" when testing cements (*i.e.* those which consist of approximately uniform grains of 20-30 mesh) all produce weaker mortars than sands having a greater range of grading, though the effect of grading is not so marked in mixtures containing a smaller proportion of cement than is used in testing.

Very minute grains, such as are found in fine powders, are generally undesirable in mortar if present in considerable proportions, as they do not sufficiently reduce the shrinkage of the mixture. Indeed, materials such as ground trass and brick-dust form a plastic paste when mixed with water, and on drying the paste shrinks so much that it cracks unduly. A small quantity of fine powder may, however, be present with advantage, as it slightly increases the hydraulic content and facilitates the hardening of the mortar (p. 49). Trass, if present, must be in a very fine state of division, as its value depends on its intimate contact with the lime used in preparing the mortar. It may therefore be used in place of the fine sand, the so-called inert material in the mortar then consisting

of suitable proportions of coarse and medium sand and fine trass or other pozzolanic material.

Under ordinary conditions, the sand used for mortar should be of the same grade (*i.e.* it should be composed of grains of as many sizes) as the sand used for concrete, though for thin joints grains of the coarsest portion may be omitted. In other words, the grading of sands for cements and mortars should be such as to secure a minimum proportion of voids (p. 35). There are no grades recognised as standards for mortar in this country, though most builders prefer a sand which leaves little or no residue on a 20-mesh sieve; few of them take the trouble to separate the larger grains. A few purchasers of sand for use in mortar insist that it shall leave no residue on a sieve with holes $\frac{1}{16}$ in. in diameter (*i.e.* on an 8-mesh sieve) and for cement mortars and grouting it is quite usual to require the sand to pass completely through a 20-mesh sieve.

If any standard were to be generally acceptable to builders it would probably specify the following, which is in close agreement with the Specification of the American Society for Testing Materials:

10-mesh . . .	No residue.
20-mesh . . .	Not more than 20 per cent residue.
50-mesh . . .	Not less than 95 per cent residue.

Even for the cheapest work, the proportion of material passing through a 100-mesh sieve should never exceed 10 per cent of the total weight of the sand.

In the United States it is customary to specify that the sand for cement grout should consist of clean sharp grains, or of screenings of hard and durable rock or gravel. It should pass completely through a No. 12 sieve; not more than 40 per cent should pass a No. 50 sieve, and not more than 6 per cent should pass a No. 100 sieve. The sand should be free from soft friable materials, shale, slate, and vegetable, or other organic matter, and it should not contain more than 5 per cent of material which will pass through a No. 200 sieve.

The methods of grading sand are fully described in Vol. I. Chapter X.

The grading of the sand grains is especially important where a water-tight mortar is desired, as in a badly graded sand the voids between the grains are both large and too numerous, so that if there is not sufficient binding material (*i.e.* cement or lime) to fill them, the mortar will be permeable. In this respect, a sand composed of grains of uniform size is of small value, as it is the presence of grains of various sizes, the smaller filling the interstices between the larger ones, which makes an impermeable mortar. Whether the sand as a whole is fine or coarse does not appreciably affect the impermeability of the mortar.

The hardness of the sand grains is generally much greater than is actually necessary, so that little difficulty is likely to arise from

using too soft a sand, though this property may need attention in the case of some non-siliceous substitutes for sand.

Preparation of Sands for Cements and Mortars.—The sands used for ordinary cements and mortars should not require much treatment, as the cost of such preparation would usually be prohibitive.

Washing (I. 384) is employed, where necessary, to clean the sands for use in cements and mortars, though even this simple process greatly increases the cost of the sand.

Screening is very often necessary for sands to be used for cements and for mortars, chiefly for the purpose of separating stones and gravel. In many small sand-pits an inclined screen (I. 451) is used, a common size being 6 ft. long and 21 in. wide, the screen being inclined at an angle of 45-70 degrees or more. In some pits, the screen is almost horizontal and is suspended from a frame; the sand is thrown on to it and the screen is rapped or shaken to aid in the separation. For larger quantities, rotary screens (I. 456) are employed and when the sand has to be washed, the washing and screening are usually combined in one apparatus.

Drying.—If the sand is damp it cannot be screened in its natural state and must either be washed through the sieves (see *Wet Screening*, I. 399), or dried before it is screened. Suitable dryers are described in Vol. I. p. 401, but as drying is expensive it is seldom used for sands required for mortar.

Other Treatments.—J. Joachim (*Ger. Pat.* 267,681, 1912) has patented the treatment of sand with hydrofluosilicic acid in order to produce gelatinous silicic acid which improves the mortar in which such sand is used, as the gelatinous silica reacts rapidly with the lime present. Other German patents have been granted for the use of fluorides for producing a rough surface on grains of sand.

Testing Sands for Mortars.—The principal tests to be applied to sands for cements and mortars are practically the same as for sand to be used in concrete. The most important are:

1. A cleanness test such as that described in Vol. I. p. 244. "Dirt" in sand for use in mortar is also readily recognised by stirring the sand with water in a tall glass vessel and allowing the mixture to stand for twenty minutes. Any material which has not settled in that time may usually be regarded as "dirt," though it may contain some of the finest grains of sand.

2. A grading test showing the proportion of sand in each of the principal sizes of grains, or plotted on a graph-sheet as in Fig. 12 (I. 216).

3. A microscopic examination to ascertain the shape and size of the grains (I. 241).

4. The weight of the sand per cubic foot or the equivalent volume-weight, determined as described in Vol. I. p. 259.

5. A determination of the strength of the mixture of sand and binding material in various proportions (I. 265).

6. A chemical analysis (this may be necessary if the sand is to be used for very high-class work) (I. 237).

For special purposes it may be desirable to make other tests, such as the tensile strength of a mixture of the sand with Portland cement, or to determine the percentage of soluble salts present.

CHAPTER IV

THE USE OF SANDS IN PLASTERS

THE term "Plaster" includes a number of plastic materials which are applied to the surface of bricks, stones, or wood in order to produce a moderately smooth and level surface. The same term is also applied to substances such as plaster of Paris and to the various cements of analogous composition which are used without any admixture (except water); these are outside the scope of the present chapter, which deals only with plasters containing sand or equivalent material. In this restricted application of the term, a plaster is very similar to a mortar, though used for an entirely different purpose. Such plasters include:

Cement plasters, which are really cement mortars (p. 43) and consist of sand and Portland cement.

Lime plasters, which are really mortars and consist of sand and lime.

Plaster of Paris plasters or *Gypsum plasters*, in which calcium sulphate or plaster of Paris is used instead of lime. This mixture is sometimes termed "white cement."

Stucco is a term used to designate all external plaster work, either lime or cement plaster being used. It is also used to define some forms of internal plastering. Common stucco, used for external work, generally consists of 1 part of hydraulic lime and 3 parts of sand.

Sgraffito and *Depeter* are plasters made with Portland cement and sand in the proportion of 1 : 3.

Rough cast or *pebble dashing* is a plaster or mortar made of lime, sand, gravel, and, where possible, hair.

As such plasters are required to cover large areas and to retain their original appearance, it is necessary to pay special attention to the proportions in which the various ingredients are mixed. Lack of adhesion and cracks in ceiling and wall plasters are usually due to lack of care or skill in the preparation of the plaster and particularly the use of (a) too small a proportion of sand, (b) a sand containing too much fine material, and (c) too long an interval between the mixing of the plaster and its application—this is particularly the case with cement plasters, which set rather quickly.

Plasters such as those mentioned on p. 55 are composed essentially of two kinds of materials, (a) a binding agent such as Portland cement or lime, and (b) sand or other non-plastic material. The binding agent when mixed with a suitable proportion of water usually forms a plastic paste which, in time, dries and forms a hard mass of smaller volume. This shrinkage is generally irregular, as the loss of water at the surface of the mass is naturally much more rapid than in the interior. The outer layers of the paste are quickly dried by being in contact with the atmosphere, and the contraction which takes place closes the pores in the exterior of the mass and prevents the loss of water from the interior, with the result that the exterior contracts on account of its loss of water, whilst the interior of the mass retains its original volume. The result is the development of a pressure on the interior of the mass. As the centre can only be compressed to a limited extent, the pressure of the exterior on the interior becomes so great that the particles comprising the former are unable to hold together, and the stress can only be relieved by some parts of the mass breaking away from the other parts and forming cracks.

To avoid the development of these stresses and the resultant cracking and falling away of the plaster, a non-plastic material, such as sand, must be mixed with the binding agent in such a proportion that the binding agent merely covers the particles of sand with a film of plastic paste, this film being so thin that its surface tension and that of the sand are sufficiently strong to ensure ample adhesion of the binder to the sand and *vice versa*. If a powerfully adhesive binder is used, such as Portland cement, a very thin film around each grain of sand will suffice, but with a weaker and more voluminous binder, such as lime, a thicker film is essential. The necessary thickness or thinness of this film is the chief factor which determines the relative proportions of binder and sand. It is obvious that if too little binder is used the grains of sand will not be sufficiently covered, and too large a proportion of sand will necessarily have the same effect. Precisely the same principle is used in the manufacture of pottery, the plastic clay or binding agent being "let down" with flint, sand, or other non-plastic material, until all risk of damage due to shrinkage is avoided.

In some plasters, a binding agent is used which expands instead of shrinking, this expansion being the result of a chemical combination of the mass with water. This expansion, like the contraction, also tends to be irregular and is liable to cause trouble unless precautions are taken to add lime or other plastic material, or to adopt some other method of avoiding cracking or other defects.

As the binding power of a sample of lime or cement varies as a result of slight variations in its manufacture, the plasterer must test his materials very thoroughly or, as is more usual, he must work in the hope that the proportions in which he mixes them will produce a satisfactory result. If he is fortunate, the cracking may not occur for several months after the ceiling or other plaster

work has been finished; in a very bad case, the cracks may be observed within a few weeks of the plaster being placed in position.

From the foregoing statements, it will be realised that such plasters are really mortars of superfine quality; they are composed of the same ingredients (p. 43), and the chief distinction between such plasters and mortars lies in the greater care and skill exercised in the selection and mixing of the materials.

Sand and Plaster of Paris.—Plasters consisting principally of calcined gypsum (*i.e.* plaster of Paris) are sometimes mixed with white sand of moderate fineness (20-50 mesh) so as to cheapen the material. In such mixtures, the sand sometimes provides channels for the crystallisation of the plaster of Paris, and these aid in increasing the speed of setting. Unfortunately, the presence of sand in association with plaster of Paris decreases the strength of the latter.

Sources of Sand for Plasters.—The sands which are suitable for use in plaster must generally be white or very pale in colour, so that many of the sources of sand for mortar and concrete are not available for the plasterer's requirements. For ordinary plaster work, highly siliceous sands are almost wholly used, though for special work other sands and crushed rocks may be employed. Common sands, for example, may be used quite satisfactorily for rough-cast work.

Silver sand is used for cement-plasters where a smooth surface with a fine texture and light colour is required.

Pit sands are largely used if they are sufficiently pure and require little treatment, and *river sands* are also used to some extent (I. 104). Where river sand is used, it should preferably be obtained from a clear running stream, as the sand is then more likely to be clean than if taken from a sluggish river.

Sea sand may be used after being well washed and exposed to the weather for about six to nine months, but in most cases a more suitable sand should be used, if it can be obtained.

Sand for most of a plasterer's work should be specified as "fresh-water, river, or pit sand, free from earthy, loamy, or saline material, well screened and washed if necessary."

Crushed felspar, coke-dust, and pumice stone have been used in place of sand in special forms of plaster.

Crushed spar, barytes, slag, ground glass, and brick-dust are used in some cases in place of part of the sand.

Marble-dust is used in place of part of the sand in "marble-setting stuff" which forms a finishing coat to some plaster work. The marble-dust should be as coarse as the sand. Marble-dust has also been used for finishing stucco since the time of the ancient Greeks and Romans; the latter used it at Pompeii and Herculaneum.

The chemical composition of sands for plasters is more restricted than for mortars, as a purer sand is required. Generally a fairly pure, siliceous sand is employed, and where colour is important

the sand should be as free as possible from any coloured impurities, though there is seldom any need to insist on the sand having less than any specified percentage of impurity as shown by chemical analysis.

The presence of mud, clay, or carbonaceous matter in sand used for plasters is very harmful and, if the plaster is used for exterior work, causes its rapid disintegration (see also p. 48). For this reason it is desirable to remove from the sand all the particles small enough to pass through a 200-mesh sieve. This is best effected, if necessary, by washing the sand.

Siliceous sands for making plaster should be perfectly free from soluble salts as these make the plaster difficult to dry, and the salt rising to the surface causes "scumming," which discolours any wallpaper, paint, etc., placed on it and tends to render the walls permanently damp. Soluble salts in the sand may also cause the plaster to flake, especially if it is exposed to the action of the weather. For this reason sea sands should be avoided on account of the soluble salts they contain (see also l. 156).

The shape of the grains of sand used for plasters is of more importance than in mortars. For plasters a sharp sand is desirable, and for this reason some pit sands are generally preferable to some river sands, as they are more regular, but if they contain any appreciable amount of loam or clayey matter they should be washed before use.

Some river sand is not really satisfactory, on account of the roundness of the grains; it may be used for making white cements, internal partitions, and "setting stuff," where the roundness of the grains is not so serious a defect.

The size of the grains of sand is not of great importance from the point of view of strength of the plaster, though the size selected should be regulated according to the nature of the plaster desired. Fine sands must be used where a fine plaster is required, whilst where a coarser plaster is required a correspondingly coarse sand may be used. For "coarse stuff" a coarse sand is preferable, but the "finishing coat" should contain fine sand so as to give a smooth surface. For common stucco work, where a smooth surface is required, the sand should pass completely through a 12-mesh sieve.

The sand used for plasterer's putty should be very fine, so as to give a smooth paste, and for this reason only that which passes through a 30-mesh sieve should be used, so as to exclude any coarse particles.

Fat limes are generally best to mix with a fairly coarse sand, whilst hydraulic limes usually produce the best results when mixed with a fairly fine sand. It is not usually necessary to grade the sand carefully when it is to be used in plaster, though a well-graded sand, with its largest and smallest particles within the limits mentioned above, is superior to a sand in which all the grains are of approximately the same size.

The methods of grading sand to make it suitable for plaster work are described on p. 35.

Preparation of Sand for Plasters.—The sand chiefly used by plasterers is not usually prepared in any special manner, except that it is generally screened (I. 441) to separate the coarser particles. It may also require to be washed (I. 384) to remove clayey matter and "dirt," and some architects always specify the use of washed sand.

In that case, the washing and screening are usually combined as described in Vol. I. p. 399. If screening is sufficient without any washing, one of the screening devices described in Vol. I. pp. 441-468 should be used.

Drying.—If it is necessary to dry the sand, one of the dryers mentioned in Vol. I. pp. 401-413 may be used.

Testing Sand for Plaster.—The principal tests which may be applied to sand to be used for plasters are the same as those given for mortar sands at the end of Chapter III.

CHAPTER V

THE USE OF SAND IN ROAD CONSTRUCTION

SANDS are employed to a considerable extent in road construction, the principal uses being :

- (a) The road surface itself (sand roads).
- (b) Mixed with other materials (sand-clay, gravel (macadam), concrete, and asphalt roads).
- (c) As a filler between blocks of dressed stone.
- (d) As a bedding or foundation for roads.

SAND AND SAND-CLAY ROADS

Sand as a road-surfacing material is satisfactory when a little sand is merely sprinkled on the surface to prevent slipping. For this purpose, the sand should be very hard, preferably a siliceous sand, containing but little dust and practically no loam and clay. The grains should be sharp and angular, and fairly fine, though not excessively so. Where the surface of the road for a depth of several inches is made of sand, however, as in the so-called sand roads, it is generally very bad for traffic of all kinds, especially where the sand is pure and contains no binding material. Such roads are extremely dusty in dry weather, and are only moderately satisfactory when they are wet; consequently, for the greater part of the year, they are a source of dissatisfaction, sometimes being even worse than muddy roads. Sand roads are never made nowadays, except in remote areas where the ground is itself sand, the road in such cases being merely a levelled part of the tract of country. In such undeveloped districts the sand will be improved and the particles will bind together better if a suitable proportion of clay and loamy matter is added, and, for the same reason, a sand which naturally contains a little clay or loamy soil is preferable for sand roads to a sand which is perfectly clean. Sands which consist of angular grains are also preferable to those with rounded grains, as the former interlock better and do not roll about so much. The presence of fine dust in the sand improves the surface of the road by decreasing the mobility of the sand; it also increases the capillary attraction of the sand and diminishes the percolation

of water, so that the road retains its water much more easily and is, therefore, stronger and more satisfactory. A road wholly composed of very fine sand is objectionable, however, as in windy weather the sand may drift like snow and spoil the surface of adjacent land as well as rendering the use of the road unpleasant and often almost impossible.

When the sand is mixed with the materials used for making a road, the results are much more satisfactory, as they combine the good qualities of both the sand and other ingredients. Thus, in a road made of a mixture of clay and sand, the clay aids in binding together the particles of sand and thus overcomes to some extent the disadvantages of the sand when used alone. Hence, roads made of a mixture of sand and clay are often quite satisfactory in remote country districts where the required materials can be obtained economically. On the other hand, such roads are very muddy in wet weather.

About 60-70 parts of sand to 30-40 parts of clay or soil usually gives the most satisfactory results, though equal parts of sand and loam sometimes produce a suitable road surface. The presence of an excessive quantity of sand is undesirable, as the surface of the road will not be sufficiently durable and will disintegrate rapidly. Mixtures containing less than 50 per cent of sand are not usually satisfactory, as in hot weather the mixture tends to shrink excessively and causes cracks in the road surface. The proportion of voids in the raw sand should be about 30-40 per cent, so that about this quantity of clay is necessary to fill up all the interstices between the grains of sand. The proportions of sand and clay in a natural or artificial mixture may be determined as described in Vol. I. p. 246.

When the correct proportions of clay and sand are used (they vary with each sand and clay), the road surface will become slightly glazed and will offer considerable resistance to abrasion. The layer of sand and clay mixture should be at least 6-8 in. thick in the centre, and 4-6 in. at the edges of the road.

The sand used for mixing with the clay for patching roads of this kind should be fairly pure and siliceous, mica being the most objectionable impurity, so that no sand should be used if a considerable proportion of this constituent is present. The sand should be as coarse as possible, and should be so graded that when mixed with the clay in the proportions 1 of clay to 2 of sand, it is practically impervious to water. The best results are obtained by the use of a sand containing 45-60 per cent of grains between 10- and 60-mesh, this proportion consisting of equal parts of 10-20 mesh, 20-40 mesh, and 40-60 mesh.

GRAVEL AND MACADAM ROADS

Gravel and macadam roads consist of pebbles 2 in. diameter, the interstices of which are filled with smaller pebbles or stones and with sand, or with a mixture of sand and clay. It is essential

in such roads that the various materials should be well compacted together, so that when the surface is rolled a good, strong road is produced. Badly compacted roads are very unsatisfactory, as wheels sink in and increase the tractive resistance. In addition, the surface is more permeable to water, rapidly softens, and ruts readily form. To produce a good gravel road it is therefore necessary to grade the gravel and sand in such a manner that each particle has the greatest possible contact with the particles around it. The sand grains should usually have their interstices filled with some form of binder, such as clay or soil, so as to increase still further the impermeability of the road. The fine dust scraped from a road prior to repairing it is also useful, as it often has slightly hydraulic properties when wetted, and so helps still further to bind the particles of stone and sand together. This additional binding action works more satisfactorily with an angular aggregate than when rounded pebbles are used.

John McAdam, whose name will always be associated with roads of this type, used to recommend that little or no road dust should be added to the materials used for making or repairing a road; on the contrary, he relied on the dust being produced by the crushing action of vehicular traffic on the surface of the road, the dust so produced being rolled into the surface by succeeding vehicles. The use of limestone as the aggregate is an advantage in this respect, as it rapidly produces sufficient fine dust to bind the surface of the road in an effective manner.

The chemical composition of the sands used in constructing gravel roads is not of great importance, provided that mica, slate, and other flaky materials are either absent or present in only small quantity. The most suitable sand is composed almost wholly of silica in the form of quartz, but calcareous sands can be used, though they are softer and, therefore, wear away rapidly. They have, however, the advantage that in wearing away they produce their own binder and so are cemented into a solid and strong mass much more readily than is the case with highly siliceous materials.

Fine, clean siliceous sands are very satisfactory for forming road surfaces on account of their durability, but they must be supplied with some other binding material such as clay or soil, as they possess little binding quality of their own. An impure or clayey sand is more satisfactory than a purer sand, as, if clay is present in proportions not exceeding 20 per cent, it assists in binding together the coarser materials; but larger proportions of clay are undesirable as they cause the roads to be more readily affected by frost. Ferruginous matter, when clay is also present, is very useful in the sands used for gravel roads, as it aids in consolidating the surface of the roads, but iron compounds alone do not have any appreciable effect. Grains of sand which are coated with iron oxide and clay, or which contain clay ironstone (i.e. iron ore cemented by clay), have a great cementing power and are,

therefore, very satisfactory. Such sands are especially useful where a roller is not available, or when only a limited supply of water is obtainable for washing in the binder. Low-grade iron ore is sometimes intentionally added to a sand to produce an artificial mixture such as that mentioned above. The sand used for gravel roads must usually be obtained locally, as the cost of transporting it over a long distance would be prohibitive. Fortunately, as previously stated, almost any kind of sharp sand can be used.

The sand used for filling the interstices between the coarser materials often occurs in close association with the latter.

The **shape** of the grains of sand used for gravel roads is of great importance where a durable surface is required. Sharp, angular sand particles are desirable and form a more durable surface than rounded grains.

The **grading** of the sand is also of great importance, though very little attention has been paid to it. This is partly the result of ignorance and partly due to a desire to avoid expense in making the road, though such apparent savings are often wasteful in the end. As explained in Chapter II., a well-graded sand, consisting of grains of different sizes, forms a much more impervious mass than sand in which all the grains are uniform in size.

Unless the conditions are exceptional, the sand should not contain more than 20 per cent of material which passes through a 100-mesh sieve, as too large a proportion of very fine particles tends to make the surface of the road too soft to resist the traffic. When, for the sake of cheapness, a sand containing an excessive proportion of clayey matter is used, the result is a dirty and dusty road of low durability.

The method of grading sand for roads is the same as that described on p. 35.

The **hardness** of the sand used partly determines the durability of the road. A siliceous sand composed of almost pure quartz or made by grinding chert, trap, or similar rock, gives the most durable road surface. An artificial sand made by grinding limestone to dust is commonly used, but it is much softer and is, therefore, less durable than siliceous sand.

CONCRETE ROADS

Concrete roads consist of an ordinary concrete aggregate and sand, bound with Portland cement to form a hard, strong mass. The sand used in the construction of such roads should be the same as for other forms of concrete and is fully described in Chapter II., so that no further description is needed, though the following specification recommended by the National Canadian Conference on Concrete Road Building in 1916 is interesting: "The fine aggregate shall be natural sand or screenings from hard, tough, durable,

crushed rock or gravel, and shall consist of quartzite grains or other equally hard material graded from fine to coarse with the coarse particles predominating. When dry, the sand shall pass through a screen having four meshes per linear inch, not more than 25 per cent of it shall pass through a sieve having fifty meshes per linear inch, and not more than 5 per cent of it shall pass through a sieve having one hundred meshes per linear inch. It shall not contain any vegetable or other deleterious matter, nor more than 3 per cent by weight of clay or 'loam.' Routine field tests shall be made on the fine aggregate as delivered. If more than 5 per cent of clay or loam by volume settles out after one hour's shaking in an excess of water, the material represented by the sample shall be held pending laboratory tests. The fine aggregate shall be of such quality that mortar composed of one part of Portland cement and three parts of fine aggregate by weight, when made into briquettes, shall show a tensile strength (at seven and twenty-eight days respectively) equal to, or greater than, the briquettes composed of one part by weight of the same cement and three parts of standard Ottawa sand. The percentage of water used in making the briquettes of cement and fine aggregate shall be such as to produce a mortar of the same consistency as that of Ottawa sand briquettes of standard consistency."

A suggested specification issued by the British Manufacturers of Portland cement is as follows:

"No natural deposits of sand and gravel shall be used without washing, screening, and grading to comply with the conditions hereinafter laid down. No aggregate shall be used which is not hard and tough, or which is laminated and upon crushing breaks down into flat elongated particles. Soft or porous materials such as broken brick, breeze, etc., shall be prohibited. All aggregates shall be clean and free from clay, dust, vegetable, and other foreign matter. Care shall be taken that the aggregate is not contaminated with mud, etc., after delivery to the site of the work. Sand or fine material shall all pass through a $\frac{1}{4}$ -in. square opening, but not more than 10 per cent by weight shall pass through a sieve having fifty meshes per linear inch. The grading from the maximum sizes shall be regular and no material shall be used which contains a large proportion of particles of approximately one size."

Concrete is also used as a base or foundation for brick roads. For that purpose the National American Paving Brick Manufacturers' Association requires that the sand or other fine aggregate "shall consist of clean sand or screenings from hard, durable rock, gravel, or slag, free from soft friable material, shale, or slate, vegetable or other organic matter, and that it shall not contain clay or silt in excess of 5 per cent by weight. The sand or fine aggregate shall pass completely through a screen having openings $\frac{1}{4}$ in. in diameter and shall be uniformly graded."

BITUMEN-CONCRETE ROADS

Bitumen-concrete roads consist of a base of broken stone and a wearing surface composed of a concrete with a bituminous cement binder. The sand used for mixing with the coarse aggregate should have the same general properties as for ordinary concrete roads, but a much smaller proportion—usually only 3-10 per cent—of sand is used. The grains should be moderately sharp, but they should not be either excessively sharp or smooth and rounded.

SHEET-ASPHALT PAVEMENTS

Sheet-asphalt pavements consist of a foundation of concrete, macadam, or other suitable material covered with a binder course composed of broken stone cemented by an asphaltic cement with or without the addition of sand. This is in turn covered by a wearing coat consisting of sand, dust, and asphaltic cement. For the *binding course* sand is not used, the finest grade of material consisting of particles varying from $\frac{1}{8}$ - $\frac{1}{2}$ in. diameter. Dust is undesirable. The grains should be as hard as possible and angular, as smooth or rounded grains render the road less durable.

The *wearing coat* consists chiefly of sand, which should have the same properties as for concrete (p. 26). Sands from the Lower Greensand of Surrey and Bedford and Portlandian sand from Oxfordshire, have been used for this purpose. The presence of a little clay or soil is no disadvantage, as it acts as a filler and so helps to fill the voids. It should not be present in more than small quantities, however, and it should not be sufficiently plastic to form a coating over the grains, or it will be likely, when passing through the heated mixer, to be burned on to the sand particles, and so prevent the asphaltic cement from adhering properly to the sand.

The grading of the sand (p. 35) is of great importance. Until very recently, little attention was paid to this, but it is now realised that adequate grading is essential to the production of a hard durable surface. A sand composed almost wholly of grains of a single size will seldom have ideal working properties without admixture, so that an artificial sand must usually be prepared. Table XXV. shows what Richardson and Forrest respectively regard as the ideal grading of sand for sheet-asphalt pavements. The sand used for a road subjected to heavy traffic is finer than that for light vehicles, because heavy traffic passing over coarse sand would soon fracture the large grains, leaving the fragments loose and in a state in which they would tend to grind together and also allow the entrance of rain-water, so that rapid destruction of the road may occur. If, however, a fine sand is employed, fracture is less likely to occur and the surface material retains its strength and cohesion.

SANDS FOR ASPHALT ROADS

TABLE XXV.--STANDARD GRADINGS FOR SAND FOR SHEET-
ASPHALT PAVEMENTS

Grade of Sand.	Passing Sieve No.	Richardson's Gradings.		Forrest's Grading.
		Ideal for Heavy Traffic, per cent.	Permissible for Light Traffic, per cent.	Per cent.
Dust	200	0	0	0
Fine	100	17	26	..
	80	17	..	20-30
Medium	50	30	30	..
	40	13	13	Not over 40
	30	10	..	..
Coarse	20	8	..	..
	10	5	30	20-30
Very coarse	8	0	0	Not over 10

The *filler* which is used to occupy the interstices between the sand grains so as to leave as low a proportion of voids as possible and, therefore, to economise in the amount of cement required, usually consists of a fine sand produced by crushing limestone to a flour-like powder. Portland cement is also used, though less frequently, and is very satisfactory for heavy traffic or where the roadway is often wet. Whatever type of filler is employed, it is essential that it should have a large volume-weight (1. 222), as the greater the weight per cubic foot the greater will be the density of the surface of the roadway. At least 60 per cent, and preferably 75 per cent, of the filler should pass through a 200-mesh sieve.

The inert material of the wearing coat (consisting of sand and filler) should contain 10-20 per cent of material which will pass through a 200-mesh sieve. Where the asphalt itself contains fine inert matter, this must be taken into consideration; for instance, Trinidad asphalt contains about 44 per cent of such material.

An excess of fine dust in the sand used for asphaltic roadways and pavements is very undesirable, as it increases the amount of asphalt required, tends to make the mixture soft and yielding, and makes the hot material difficult to spread.

The grading of the complete pavement or road-surfacing material specified by the American Society for Municipal Improvements is given in Table XXVI.

[TABLE

TABLE XXVI.—GRADING FOR ASPHALT PAVEMENT

	Per cent.	Per cent.*
Bitumen	9.5 to 13.5	..
Sand passing 200-mesh .	Not less than 10	Total not less than 25
.. .. 80 .. .	10 to 35	
.. .. 50 .. .	4 .. 35	Total not less than 15 to 50
.. .. 40 .. .	4 .. 25	
.. .. 30 .. .	4 .. 20	
.. .. 20 .. .	4 .. 12	
.. .. 10 .. .	2 .. 8	Total 10 to 35
.. .. 8 .. .	0 .. 5	

A grading used in Fulham and other parts of Surrey, etc., which has proved quite satisfactory is shown in Table XXVII.

TABLE XXVII.

Mesh of Sieve.*	Per cent.
200	18
100	17
80	17
50	35
30	6
20	4
10	3

* The sieves are to be used in the order named.

ASPHALT-CONCRETE PAVEMENTS

Asphalt-concrete pavements, which are used more extensively in the United States than in this country, have a wearing surface composed of a concrete aggregate with an asphaltic cement and are very similar to bituminous concrete, but differ from sheet-asphalt pavements in containing a much coarser aggregate. In each case, the material which passes through 100-mesh and 200-mesh sieves respectively is usually composed of naturally fine mineral matter to which may be added finely ground limestone; the greater part of the remaining material usually consists of sand, the coarsest portion being gravel or stone chippings. The sand used in asphalt-concrete pavements should have the same properties as that used for bituminous concrete.

In **Bitolithic Pavements** the wearing coat consists of aggregate in pieces from 3 in. diameter to dust. The sand should have the same properties as for other types of road; the grading of the material used for two existing road surfaces is shown in Table XXVIII.

TABLE XXVIII.—GRADING OF MATERIAL FOR BITULITHIC PAVEMENTS (AGG.)

					No. 1.	No. 2.
					per cent.	per cent.
Bitumen					7.6	7.02
Mineral aggregate passing through 200-mesh sieve					4.9	4.58
"	"	"	"	100	4.6	3.99
"	"	"	"	80	3.2	2.76
"	"	"	"	50	7.3	7.88
"	"	"	"	40	3.1	1.27
"	"	"	"	30	2.4	2.39
"	"	"	"	20	2.2	2.13
"	"	"	"	10	5.1	3.77
"	"	"	"	$\frac{1}{4}$	9.1	4.85
"	"	"	"	$\frac{1}{2}$	19.3	12.75
"	"	"	"	1	31.2	46.61

Numerous patents have been granted for various mixtures to be used for asphalt-concrete roadways, and much litigation has risen therefrom. Three of the most important of these patented mixtures are (a) that used in the **Amlesite pavement**, which is similar to the Bitulithic pavement, (b) that used in the **Warrenite pavement**, in which sand forms the bulk of the wearing coat, and (c) the well-known **Topeka mixture**, which has the grading given in Table XXIX.

TABLE XXIX.—TOPEKA MIXTURE

					Per cent.
Bitumen					7.11
Mineral aggregate passing through 200-mesh sieve*					5.11
"	"	"	"	40	18.30
"	"	"	"	10	25.55
"	"	"	"	4	8.22
"	"	"	"	2	Not over 10

* The sieves to be used in the order named.

The American Society for Municipal Improvements recommends the grading given in Table XXX. for asphalt-concrete pavements, as it has been ascertained that it does not infringe any of the patents just mentioned.

TABLE XXX.—GRADING OF MATERIAL FOR ASPHALT-CONCRETE PAVEMENT

					Per cent.
Bitumen					7.9
Mineral matter passing 200-mesh					7.10
"	"	"	"	80	10.20
"	"	"	"	40	10.25
"	"	"	"	20	10.25
"	"	"	"	8	10.20
"	"	"	"	4	15.20
"	"	"	"	2	5.10

ASPHALT-MASTIC PAVEMENTS

Asphalt-mastic pavements consist of mastic, asphalt, and sand. The material known as mastic in the pavement-making industry is a mixture of 12-18 per cent of asphalt with 82-88 per cent of a finely divided inert material, which may be either a siliceous sand, limestone dust, iron oxide, or alumina, or mixtures of these materials. The mastic is heated to 350°-400° F. (177°-204° C.) and is then made into cakes weighing 50-60 lb. each. These blocks are melted and mixed with an additional quantity of asphalt and sand when required. The sand may be either siliceous or calcareous, but the latter must not be used in the vicinity of acids.

The grading should be adjusted so as to secure a minimum of voids (p. 35), and no particles of the sand should be more than $\frac{1}{4}$ in. diameter.

The grading shown in Table XXXI. may be used for various purposes.

TABLE XXXI. GRADING FOR MASTIC PAVEMENTS (Abraham)

	10-200 Mesh, per cent.	$\frac{1}{4}$ in.
Material for :		
Footpaths	20	41
Cellars	15	40
Corridors, stairs	15	35
Shops	12	33
Cold storage	15	35
Acid tank rooms :		
Bottom course	15	35
Top course	12	33
Reservoirs	5	30
Swimming-pools	5	31
Bridges :		
Bottom course	5	30
Top course	12	33
Concrete bridges	10	30

Asphalt Paving Blocks are made with a mixture of broken stone or grit of $\frac{1}{4}$ in.-10-mesh and sand, at least 20 per cent of the sand or other inert material passing through a 200-mesh sieve and not more than 3 per cent remaining on a 10-mesh sieve. A minimum of voids is desirable, as in concrete (p. 35).

Expansion Joints made of bituminous material consist of sand, asphalt of high fusing point, and shoddy dust in the proportion of 1 : 1 : $\frac{1}{2}$. Sheets of this material are placed between the pavement and the curb or across the pavement so as to take up stresses due to changes in temperature. The sand for this purpose may be limestone or siliceous sand, crushed slate, or other similar

material, and should be fairly fine. Its general properties should be the same as those of sand for sheet-asphalt pavements (p. 65).

SAND AS A FILLER

Sand as a filler in roads composed of bricks, wood, or stone blocks has long been used, the filler being placed between the joints in the materials so as to prevent the movement of the blocks and to avoid their edges being chipped whilst in use. There is seldom any need to mix anything with the sand, and as a matter of fact, sand alone has long been used as a filler for brick and wood block roads, though its use for wooden blocks in roads has now been largely abandoned. Sand as a filler for roads made of brick has the advantage of being very cheap and no time is lost in opening the road, as is the case when a wet filler is used. If it should be desired to break up a sand-filled road, the bricks themselves need not be damaged, as the filler does not cement them together.

The quality of sand used as a filler for bricks, etc., is not of great importance, but it should contain a considerable proportion of material finer than 20-mesh and should not contain much more than 10-15 per cent of clay or "dirt," though the presence of these materials is less serious than where some form of binder is used, which is required to adhere to the particles of sand. The sand should be quite dry so that it may be readily pressed into the joints between the blocks.

Cement Grout is sometimes used as a filler for roads made of bricks and wooden blocks. The sands used for this purpose are described in Chapter III. For road work not more than 1 per cent of "dirt" should be present in the grout, and the grading should be fairly uniform, from 20- to 100-mesh.

A **Tar-sand Filler** is sometimes used for roads made of either bricks or stone blocks. The sand in such a mixture renders the tar less susceptible to changes in temperature. The sand for this purpose should be the same as that for asphaltic roadways (p. 67) and should be quite clean. The coarser the sand, the less tar will be required, but the sand should not be so coarse as to prevent the production of thin joints. It should usually pass completely through a 20-mesh sieve.

SAND AS A BEDDING

In order to prevent the upper part of the road from being forced into the ground, a bedding of some kind is employed. In macadam and similar roads, a layer of sand, crushed stone, or even ashes, is interposed to prevent this sinking. It has been suggested that, for roads on a clay soil, the clay and "dirt" should be removed down to a sufficient depth and the space filled with sand so as to prevent settlement, which would otherwise inevitably occur. The cost of this method is usually prohibitive. In roads composed

of blocks of stone or wood, or even bricks, a bedding course of sand is generally laid between the foundation and the blocks.

The chief disadvantages of sand as a bedding course are :

1. It is very difficult to make the bed of equal density throughout, especially where it is laid thickly.

2. The sand tends to rise between the joints of the blocks and so prevent the filler from reaching to the whole depth of the bricks or blocks ; this is especially the case where fine sand is used.

3. The sand is liable to be irregular in its moisture content.

4. The sand is liable to leak away through cracks into man-holes, sewers, etc., so that the level of the road is gradually lowered—usually in an irregular manner.

In spite of these disadvantages sand is still largely used as a bedding course.

Selection of Sand for Road-beds.—Almost any clean, fine sand of moderate sharpness can be used for the foundations and bedding of roads, but a highly siliceous sand containing at most 25 per cent of clay or "dirt" is the best. "Dirt" or loam is undesirable, as, if the bedding course becomes wet during use, the fine particles of clay and loam may be washed to the bottom of the bed and so cause the blocks to sink and produce a very uneven road-surface. Vegetable matter in the sand is also very undesirable, as it decays in use, is liable to be washed out, and allows the blocks to sink.

The American Society of Municipal Improvements recommends that not more than 10-25 per cent of loam or clay should be present in the sand used for bedding wooden blocks, whilst for brick roads the National Paving Brick Manufacturers' Association specify that the sand shall not contain more than 15 per cent by weight of clay or loam.

Moisture is very undesirable in sands used for bedding roads, as wet sands have a greater volume than dry ones, especially if the sand is fine. For this reason, if a sand contains moisture irregularly distributed, the bed, on drying, will vary in thickness and so give the road a bad surface. Hence, the sand should be perfectly dry when it is laid.

The *texture* of the sand is also important. It should consist of sharp angular grains so as to obtain a maximum of interlocking and a minimum of movement. Rounded grains, especially if smooth, tend to roll and the bed is more easily displaced. For this reason, sand composed of rounded grains should not be used as a bedding material.

The *size* of the grains of sand is very important. The sand should be so fine as to feel soft and velvety ; it will then form a dense, solid bedding. The finer the grains the better will be the quality of the bed.

Mixtures of cement and sand are sometimes used for bedding courses, as they are less mobile than loose sand and so have an advantage over the latter. Such a bedding adheres both to the foundation below and to the blocks above, so that a very rigid

road-surface is produced. The bedding is made by laying a dry mixture of cement and sand in the proportions of 1 : 3 or 1 : 4 and then laying the bricks or blocks on this bed. The latter are next sprinkled with water, thus converting the mixture of cement and sand into a mortar, though this is not as good as a properly mixed mortar, because the amount of water which can gain access to the bed is limited and it is difficult to wet the whole of the mass uniformly.

In some cases the cement and sand are properly mixed with water before being laid, and the bricks are then placed in position on the bed before the mortar sets. The sand used for such beddings should have exactly the same properties as that used for cement-sand mortars (p. 48).

Preparation of Sands for Use in Road Construction.—Wherever possible, sands in road-making should not undergo any treatment, as the cost of such preparation greatly increases the cost of making the road. In some cases, however, it may be necessary to wash or screen the sand, especially where a clean and carefully graded product is required. Tubular or rotary sand-washers (I. 389) are very satisfactory for this purpose, especially if they are portable and a dry sand is required. In most cases the sand can be obtained sufficiently dry, but if not, some form of dryer (I. 401-413) must be used.

Screening is very desirable so as to secure a properly graded product. For this purpose, any of the methods described in Vol. I. Chapter X. may be employed, portable rotary screens being satisfactory. Where it is merely required to separate some coarse material from the sand, an inclined flat screen may be used. Where stone screenings are employed in addition to or instead of sand, it may be necessary to crush them in order to secure a product of the desired fineness.

Tests for Sands used in Road Construction.—The tests of sands for making roads are practically the same as those suggested for testing sand to be used for concrete, as much of the sand used in roads forms part of an aggregate similar to that in concrete.

The principal tests are :

1. Chemical analysis (I. 237). This is not usually important except for channels and conduits along which acids may be required to flow.
2. A microscopical examination to show the shape and size of the grains, and the nature of their surface (I. 241).
3. A cleanness test (I. 244).
4. A grading or sieving test (I. 246) to show the proportions of grains of various sizes.
5. A determination of the proportion of voids (I. 261).
6. A determination of the volume-weight or weight per cubic foot (I. 259).
7. A hardness test (I. 209). This is necessary for sand to be used for the wearing coat, though usually the hardness of any

siliceous sand is ample; the calcareous sands and various sand-substitutes are often too soft.

8. A determination of the dryness or moisture content (I. 238). This is necessary in the case of sands to be used for bedding, as there the presence of much moisture would be serious.

SUNDRY USES OF SAND IN BUILDING CONSTRUCTION

Foundations.—The use of a natural sand bed for foundations is very satisfactory from a health standpoint, provided the ground is not low-lying or water-logged. A sand bed is sometimes used as a foundation on which brickwork is built when the ground is somewhat weak. Sand is also used to form piles in peaty ground. A timber pile is driven into the ground to the required depth and drawn out again, the hole thus formed being filled with sand and the surfaces covered with concrete. The depth of such a sand pile is usually 6-10 times its diameter. Sand is also used as a bedding for concrete piles, beams, etc.

The sand used for foundations should have the same properties as the sand used for bedding roads, except that a somewhat coarser sand may be employed for foundations. The principal properties required are: (a) the sand should be angular so as to pack well together, (b) it should be clean and free from loam or clay which may, in time, be washed out and so cause the building to sink, and (c) it should be dry, as wet sand has a greater volume than dry sand and would, later, tend to cause sinking. For further information, see pp. 71-72.

The safe bearing load of a foundation consisting of compact dry sand, well cemented and confined, is 4 tons per sq. ft. A natural bed of clean dry sand will support 2-4 tons per sq. ft.

Bituminous Fabrics are frequently treated with sand to improve their durability and appearance. Surface coatings of sand are frequently applied to roofing and floor felts—usually by sprinkling the hot felt with sand and then applying a roller. The sands for this purpose are of three kinds: dust, medium sand, and coarse sand. The chemical composition of the sand is not of great importance, siliceous sands, kieselsguhr or infusorial earth, ground limestone, or other similar materials all being used for this purpose. The medium and coarse sands are sometimes replaced by crushed red or green slate, or other coloured rock, sand which has been artificially coloured, or crushed bricks, tiles, marble, felspar, granite, sea-shells, or slag. The sand should be quite clean, as any foreign matter present reduces its adhesion to the bitumen or other material on the felt or fabric.

The *shape* of the sand grains is preferably angular, as sharp grains adhere more readily to the felt than rounded ones, though the latter are sometimes used for decorative effects.

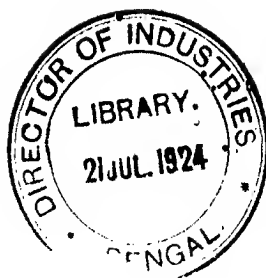
The *size* of the grains of sand depends on the use to which it

is to be put. The dust used for preventing the fabric sticking when it is rolled should not leave more than 5.25 per cent of residue on an 80- or 100-mesh sieve. The grains of medium and coarse sand may be of any convenient size, according to the effect desired. A uniformly sized sand is desirable for decorative effects, and fine material should then be avoided, as far as possible, as it also prevents the adhesion of the larger particles.

Moulded Articles such as insulators are sometimes made of a mixture of sand and bituminous material. For this purpose, silica, kieselguhr, slate, or limestone may be used, the principal properties desired being: (a) cleanness to facilitate the adhesion of the binder, (b) fineness in accordance with the size of the articles made, (c) proper grading (p. 35), and (d) angularity sufficiently marked to enable strong articles to be produced.

Preparation and Tests.—The methods used in the preparation of sands for various purposes in building construction and their testing depend entirely on the purposes for which they are to be used. Sands for foundations and bedding are prepared and tested as mentioned in Chapter IV.

Sands for ornamental purposes require to be tested in the particular direction in which ornamentation is desired, *i.e.* for uniformity of colour, grain size (I. 246), cleanness (I. 244), shape of grains (I. 241), etc. The chemical composition as shown by chemical analysis may also be important in certain cases.



CHAPTER VI

THE USE OF SANDS IN METALLURGY

SANDS are used in the metallurgical industries for various purposes, the chief of which are :

- (i.) As sources of various metals.
- (ii.) For moulding metals in the production of castings.
- (iii.) For lining metallurgical furnaces.
- (iv.) For use in smelting and refining various metals.
- (v.) For use in welding metals.
- (vi.) For enamelling metals.

SANDS AS A SOURCE OF METALS

Various metalliferous sands are important as a source from which certain metals can be obtained. Thus, auriferous and argentiferous sands and other placer sands (L. 133) provide a considerable proportion of the world's supply of gold, silver, platinum, and other precious metals. Iron-bearing or highly ferruginous sands (L. 122) are worked for the sake of the metallic iron which can be produced from them. Monazite, zircon, and other sands yield yttrium, zirconium, cerium, thorium, lanthanum, etc.

The distribution and characteristic properties of these sands have been described in Vol. I. Chapter III., and the methods used for obtaining them in Vol. I. Chapter VII., the methods of preparing them, including the separation or concentration of the valuable metallic compounds, have been described in Vol. I. Chapter IX., and the subsequent treatment of the highly concentrated ores eventually obtained from the sands is beyond the scope of this volume; information thereon should be sought in books dealing with the smelting of the respective metals.

MOULDING SANDS

The uses of sands of various kinds in casting metals and alloys are both numerous and important, and many of the difficulties experienced in using them for this purpose are primarily due to

lack of knowledge of some of the properties of the sands and of the best methods of selecting and treating these materials.

Moulding sands may be used in several different ways; for instance, very large castings are usually made by excavating a pit of ample size in the floor of the foundry—which is composed of sand and must extend to a greater depth than any casting likely to be required. In the cavity thus prepared the mould is formed by packing sand around a wooden pattern, supports being given, when necessary, by brickwork or by other simple means. Smaller castings may be made in the floor, but more usually cast-iron boxes are employed for containing the sand. For hollow castings, one or more internal pieces or “cores” are placed in the mould; these cores must at least be covered with a suitable sand and are frequently made wholly of a sandy material.

The various methods of moulding may all be arranged in two groups:

1. *Open-sand moulding*, in which the pattern is impressed in the sand forming part of the floor of the foundry or in sand in open boxes or trays, the metal being poured into the impression or mould thus made.

2. *Close moulding*, in which the mould is made in two or more parts forming a hollow interior corresponding to the pattern and to the shape which it is desired the casting should possess. The consideration of which type of mould is best for a given purpose, and of the vents, pegs, and other details of construction necessary to secure a good casting, are beyond the scope of this volume.

Three terms largely used in foundry work need brief explanation; they are:

- (a) *Green sand moulding*, in which a raw sand in its natural, undried, or “green” state is used. Green sand moulding is generally employed for malleable and chilled iron, steel, and small brass and bronze castings.

- (b) *Dry sand moulding*, in which the mould is made of damp sand, but is dried before use. Dry sand moulding is used for large castings of all kinds and for many small ones, as there is less risk of accident and better castings are more easily obtained. Cores are usually made by this method.

- (c) *Loam moulding*, in which no pattern is used, the sand being shaped by hand to the desired form. Such a mould can only be used once, so that it is only employed where many duplicate castings are not required, or where there is no objection to rough castings, as in the production of pig iron. The chief disadvantages of this method are the amount of labour involved in preparing the casting bed and the adhesion of the sand to the castings.

Materials used as Moulding Sands.—The principal materials are siliceous sands, varying from those consisting of almost pure silica to loams containing up to 40 per cent of clay or analogous material.

Moulding sands are described as “strong” when they contain

a considerable proportion of clayey matter, and as "mild" or "lean" when they are almost devoid of this material. They are described as "high silica" sands and sands with "natural bond"; the former are very mild and consist of almost pure silica, the latter are strong and contain a considerable proportion of clay or ferruginous material which forms the bond or agent which unites the particles of sand together. The "high silica" sands require an artificial or added bond in order that they may have the necessary plasticity and cohesion.

They are commonly known by the following names, which indicate the special purposes for which they are used:

Green Sands are sands which are used in their natural state and contain a certain proportion of moisture. The name has no reference to their colour and must not be confused with the "Greensands" obtained from a certain geological formation (I. 118).

Dry Sands are misnamed, as the moulds are made of damp sand, but are dried before use.

Loam is a natural or artificial mixture of clay and sand which is used for moulding large castings, pig iron, etc., usually by open sand moulding. Three kinds of loam are used:

(a) *Building loam*, consisting of black sand mixed with clay-water to give it the necessary binding power.

(b) *Coating loam*, which consists of a sharp sand mixed with clay, sawdust, and water.

(c) *Finishing loam*, which consists of fine particles separated by screening from the coating loam.

The characteristics of these various kinds of loam are described under their properties, such as chemical composition, etc.

Backing, Floor, or Black Sand is that which constitutes the bulk of the mould and acts as a support for the "facing" sand, which comes in contact with the molten metal; it gives rigidity and solidity to the mould and forms a porous backing through which the gases trapped between the face of the mould and the molten metal are able to escape. When a casting has been completed and the metal removed, the sand which formed the mould is removed (thus destroying the mould) and is put into the general sand-pile for use as backing sand. This practice is not altogether desirable, as some of the used sand is often burnt by contact with the molten metal and also on account of its containing coal dust, so that the sand gradually grows weaker with use. (See also p. 119.)

Facing Sands are used for giving a smooth face to the mould. This sand comes into contact with the pattern and also with the molten metal when the latter is poured into the mould. Other substances used for the same purpose, but applied later to the face of the mould, are sold under various names.

The only facing materials other than sand which can be classed as sand are kieselguhr, brick-dust, and silica flour. The non-sandy facings include china clay, fireclay, brick-dust, broken crucibles, talc, graphite (plumbago), "compo," siftings, coal, coko, charcoal,

cinders, sawdust, dung, etc. They are sometimes known as *blackings*.

Silica flour, *sand-dust*, and *kieselguhr* are used on account of their refractoriness, silica flour being the most useful when casting steel; all three materials are employed in dry, green sand and loam moulding. In green sand moulding, the finely ground material is applied through a porous canvas bag to the surface of the mould, the surface being afterwards smoothed by means of a trowel or "sleeker," or the powder is applied with a camel-hair brush. In some cases, the pattern is replaced in the mould and pressed so as to produce a uniform facing.

In loam and dry sand moulding the powder is made into a liquid slip with water and a little dextrin or flour, applied by means of a brush.

The silica flour is sometimes mixed with graphite or talc.

The chief difficulties connected with the use of silica flour or other finely powdered silica are that it tends to fill the pores in the surface of the mould, which may cause scabbing and "burning on" where very high casting temperatures are employed. For such purposes carbon is better. Finely ground silica may also cause trouble on account of the transformation from the high specific gravity form to the low specific gravity form when the silica is heated by the metal to a high temperature.

Siliceous sinter, mixed with a suitable quantity of dextrin solution as a binding agent, is sometimes used instead of silica flour.

Brick-dust in a very finely divided state is used in the same way as silica flour. Where a highly refractory facing is required, fire-brick dust must be used, but for brass, etc., common brick-dust will serve. It may be used either dry or in the form of a slip. The addition of a vegetable binder is usually necessary to give it the required adhesiveness. The fire-brick dust is also used in combination with other materials such as graphite.

Blackings are similar to "facings," but are chiefly composed of some form of carbon such as graphite, plumbago, coke dust, charcoal, or other carbonaceous matter. These materials are valuable, as, when heated by the metal, they liberate gases which form a film between the mould and the metal and prevent the latter from damaging the mould. The term "blackening" is also applied generally to all facings which are used in liquid form. Although some "blackings" contain silica flour, brick-dust, or other siliceous substances, their essential constituent is of a carbonaceous character as stated above.

The essential properties of facings and blackings are great fineness and sufficient refractoriness to withstand the high temperatures to which they are exposed when the metal is being cast.

Parting Sand is used to separate the various portions of the mould where the shape is complicated, and a mould consisting of two or more parts is necessary. The material usually employed

for this purpose is an old facing sand, the grains of which have been rounded and have lost all their binding power, but any sharp fine sand which is sufficiently refractory may be used. A fine, highly siliceous sand or the finest portion of sifted burnt floor sand or fire-brick dust is usually employed. Parting powders are also applied to the patterns so as to permit the latter to be withdrawn from the mould without damaging it. They may consist of a mixture of fine sand, brick-dust, or kieselgur, with a little oil—preferably paraffin—to make it repellent to water.

Core Sands are those used to form cores which determine the shape of the interior surfaces of hollow castings. They are required to withstand very severe conditions, as they are often almost wholly surrounded by molten metal.

"Compo" (an abbreviation of "composition") is a preparation used in moulding large castings, which generally consists of a mixture of fireclay and silica rock (preferably ganister) ground together with water so as to form a moderately soft paste. Broken plumbago or fireclay-crucibles, coke, coal-dust, charcoal, and blacklead (plumbago or graphite), are also included in some compos.

The rocky part of the mixture must be of a porous character, but the clay or other binder should be finely ground so as to develop its binding power to the fullest extent. Some foundry proprietors purchase the compos ready-made; they would usually find it both cheaper and better to purchase the raw materials and then mix and grind them in a building adjacent to the foundry. An edge-runner mill with a solid revolving pan is all that is needed, the roughly crushed ganister or other silica rock, fireclay, and water in suitable proportions being "ground" in the mill for about twenty minutes. Foundrymen differ greatly in the proportions of non-plastic material and fireclay they prefer in the compo; some obtain the best results with a 2:1 mixture, whilst others prefer a 4:1 mixture. The proportions of the other ingredients, when used, are equally variable.

Properties of Moulding Sands. Although the uses of moulding sands are so numerous and the properties they are required to possess vary so greatly when the sands are used for different purposes, they have certain properties in common, so that it appears more desirable to consider all the sands together when dealing with any specific property rather than to attempt to deal with all the properties of each separate kind of sand. A reference to the index will enable the reader to ascertain rapidly what properties any particular kind of moulding sand should possess.

The **colour** of a moulding sand is not usually of any great importance, though in some cases it is very useful as an indication of its nature and purity. The colour varies from almost pure white, in the case of pure silica sands or crushed rocks, through various shades of yellow and brown to a deep red colour, the tint being due to the presence of a variable proportion of iron oxide and carbonaceous matter. The depth of the colour is to some

extent an indication of the iron content, though it is by no means an accurate test. Certain well-known sands are characterised by their special colour, *e.g.* the famous yellow Frith sands and the red sands of Mansfield, Worksop, and Kidderminster.

Refractoriness.—A moulding sand must be sufficiently refractory to withstand the action of the molten metal with which it comes into contact. The extent of the refractoriness needed depends on the metal to be cast, the temperature at which it melts, and the duration of the contact. Metals such as lead, brass, bronze, etc., are cast at much lower temperatures than iron and steel, so that the sand need not be so refractory for the former as for the latter. Iron does not require so refractory a sand as does steel. On the other hand, a high refractoriness is specially important in large and heavy castings, where the heat is conducted away much more slowly than when light or thin castings are made.

The greatest refractoriness is required in casting large pieces of steel, as this material is poured at very high temperatures (between 1520° and 1600° C. when the metal reaches the mould) which approach the softening point of silica and are far higher than the fusing points of the chief impurities found in moulding sands, with the result that unless a very good refractory sand is used it is liable to fuse and adhere to the metal. This defect is called "burning on." It occurs most frequently when casting steel from converters, as in these the metal is raised to a higher temperature than in other furnaces, and consequently is more liable to fuse the surface of the sand in the mould. Steel melted in an electric furnace does not burn quite so readily as that from a converter, whilst the steel from an open-hearth furnace is still less likely to cause trouble in this direction. "Burning on" is very common where the sand is greatly compressed, as in the enclosed parts of the cores, so that the heat, not being able to escape, causes a partial fusion of the sand and makes it adhere to the surface of the metal. For this reason, only highly refractory sands should be used for cores. As "burning on" is almost wholly due to the partial fusion of the grains of sand, the best means of preventing it is to use a facing sand which is sufficiently refractory to resist the heat of the metal.

"Scabbing" is also attributed by some foundrymen to lack of heat-resistance in the sand, but whilst it may, on rare occasions, be due to this, the chief cause of scabbing is faulty ramming when making the mould.

The average temperatures to be withstood by different moulding sands are given in Table XXXII.

The refractoriness of a sand depends on the proportion and nature of the substances other than silica in the sand (see *Chemical Composition*, p. 85). The most refractory constituent of a moulding sand is pure quartz, which does not show signs of fusion, when pure, at temperatures below 1700° C. It is impossible, however, to use a sand consisting entirely of quartz grains, as it

TABLE XXXII.—CASTING TEMPERATURES

Sand for Casting.	Maximum Temperature attained.
Brass	1350° C.
Iron	1510° C.
Steel	1580°-1650° C.

lacks binding power and would not produce a serviceable mould, so that a variable proportion of substances which reduce the refractoriness must inevitably be present; this should, however, be as small as possible consistent with the production of a good mould which will produce accurately shaped, clean castings.

Almost all minerals, other than silica, which occur in sands decrease the refractoriness, and are, to that extent, undesirable, although it may be necessary to overlook the reduction in heat-resistance because of some other good quality which a sand possesses.

The effect of heat in converting quartz into other forms of silica, such as tridymite and cristobalite (I. 226), may have some influence on the production of "burning on" and "scabbing," but as this conversion is an inherent property of the silica it cannot be avoided. The extent of the conversion which in most cases must be slight—depends on the size of the particles.

As large particles of silica require a longer time for the heat to penetrate than is needed by smaller particles, the refractoriness of a sand appears also to depend on the size and shape of the particles of which the sand is composed (I. 230). The finely powdered material used for "facing" moulds should consist of almost pure silica in order that it may be sufficiently refractory to withstand the high temperature of the freshly poured metal. Heat penetrates a large piece of quartz very slowly, but a minute particle of silica flour is rapidly raised to a high temperature. Hence, the smaller the particles the greater is the necessity of using only those having a high refractoriness.

Porosity and Permeability.—These terms are frequently misused with reference to moulding sands. The term *porosity* is applied to the relative volume of the pores or interstices between the solid particles, whilst the term *permeability* relates to the extent to which gases can pass through the material. The distinction is important, as a sand may have a high percentage porosity but a low permeability, and all sands of high permeability are not highly porous. The porosity is measured by the amount of water which is required to occupy the interstices or voids in the sand; the permeability is measured by the rate at which water or a suitable gas will pass through the sand.

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Permeability is of much greater importance than porosity in moulding sands, though the latter, being readily determined, is often (erroneously) assumed to be proportional to the former.

With respect to *porosity*, sands are classed as “*open*” or “*close*,” the former having a greater porosity than the latter.

The porosity of a moulding sand is dependent on various factors, including

1. The size of the grains of sand (p. 105).
2. The shape of the grains (p. 104).
3. The grading of the sand, *i.e.* the relative proportions of grains of different sizes (p. 105).
4. The proportion of impervious material, such as clay, which is present (p. 94).
5. The dryness of the sand (p. 100).

The *permeability* of a moulding sand is most important, as when molten metal is poured into the mould any air which becomes trapped between the metal and the face of the mould may cause a defect in the casting, so that some means for permitting it to escape must be provided. As the gases cannot escape through the molten metal, they must pass through the mould itself, and therefore the latter must be sufficiently permeable to allow the gases to pass through it at a sufficiently rapid rate to prevent any damage to the casting. Gases are also occluded from the molten metal, and, if a green sand mould is used, some steam is also liberated as the moisture in the mould is evaporated. These gases and vapours must be able to escape rapidly through the pores in the mould. The scabs or wart-like projections sometimes seen on the surface of castings are due to air or other gases being trapped between the metal and the mould.

A sand should be as permeable as possible, so that the gases and steam generated may readily and rapidly escape without damage to the surface of the casting; but excessive porosity is undesirable, as the molten metal would then tend to penetrate into the mould and so give the casting an irregular surface, to which a large proportion of sand would adhere very tenaciously.

A sand with a low porosity and high permeability usually contains a large number of very minute interstices between the particles, whilst a sand having high porosity as well as high permeability probably contains a smaller number of much larger pores.

As gases can pass through much smaller apertures than liquids, the best moulding sands, when in use, have a sufficient number of pores each large enough to enable the gases to escape, but not so large as to enable the metal to penetrate below the surface of the mould. The permeability of a mould depends chiefly upon

1. The shape of the particles (p. 104).
2. The size of the particles (p. 105).
3. The amount of bond present (p. 92).
4. The amount of moisture present (p. 100).

5. The metal to be cast; a sand is not equally penetrated by different metals. Thus, a sand which gives perfectly satisfactory castings with iron does not necessarily give equally satisfactory results with lead, brass, etc. Brass and some other metals have a "searching" action on moulding sands which prematurely closes the pores in the face of the mould, so that highly refractory sands of great permeability are sometimes necessary in such cases.

6. The temperature of casting also has an important influence on the permeability of a sand.

Plasticity.—The plasticity or cohesiveness of the sand is a very important property, as upon it depends the extent to which the sand can be made into any desired shape which it retains after the pattern has been removed, and also after the molten metal has been introduced into the mould. A sand which is deficient in cohesion would not preserve its sharp edges after removing the pattern, and so would not give a casting of the correct shape. When the molten metal is poured into a mould made of a loose incoherent sand, the latter would be carried away by the flowing of the metal and the casting would be spoilt. Consequently, a moulding sand must be sufficiently strong to resist the pressure of the molten metal, both in its liquid form and during solidification. The plasticity and cohesion necessary vary according to the nature, size, and shape of the article to be cast. Where the surfaces of the casting are flat a highly cohesive sand is not necessary, but where an article with a complex surface is to be cast, a sand with a much greater binding power is required.

The plasticity and cohesion of a moulding sand are much less than those of clay, but resemble the latter in many respects. They depend on

1. The proportion of clay or other binding agents present (p. 92).
2. The binding power of the clay, or other binding agents present (p. 93).
3. The sizes of the grains of sand (p. 105).
4. The shapes of the grains of sand (p. 104).
5. The chemical composition of the sand (p. 85), though with highly siliceous sands this is of minor importance.

Sands are termed weak, medium, or strong, according to their plasticity, weak sands being those containing only a small quantity of clay or other bond and therefore very deficient in plasticity, whilst strong sands are those containing a larger proportion of clay or other bond and which therefore have a greater plasticity.

Most of the moulding sands in this country are natural mixtures of quartz grains and a bonding material such as clay or limonite (a complex and probably colloidal hydroxide of iron), and British founders usually rely either on obtaining a single sand suitable to their requirements or on mixing several sands so as to obtain a product having the desired properties. Only to a very limited extent are artificially prepared mixtures of sand and clay used

in this country; they are much more extensively used in Germany and the United States.

It is by no means difficult to match any of the well-known and highly esteemed moulding sands by using two other sands and a suitable clay; and as such artificial mixtures can be relied upon to retain a constant composition, no matter when they are made, they have an obvious advantage over natural sands with their unavoidable variations in composition and properties. The only property in a natural sand which cannot be matched in an artificially prepared mixture is the slight plasticity due to iron compounds, as this cannot, at present, be duplicated artificially, with the result that artificially prepared moulding sands produce castings with a slightly rougher face than when natural sands are used, and the withdrawal of the casting from the mould, or *vice versa*, is not quite so complete. In all probability, if more attention were paid to the use of ferruginous materials in such artificial mixtures, this difficulty could be overcome, as the production of a film of colloidal iron oxide on the particles of an iron-free material is by no means difficult. A rough yet useful test of the plasticity and cohesion of a sand is to squeeze a sample in the hand and, after releasing it, examine whether it shows an impression of the fine lines of the skin. If it does so, the sand is probably satisfactory, but may contain an excess of clay or water. The test should, therefore, be repeated on mixtures of the sand with various proportions of an almost pure silica sand. It will then be easy to judge whether the moulding sand is improved or harmed by the addition of more sand.

Further information on the plasticity of moulding sands will be found under *Mineralogical Composition* (p. 90).

Binding Power.—The term “binding power” is sometimes applied to a sand when referring to its plasticity (p. 93). This is a mistake, as the term “binding power” should be restricted to the power possessed by some materials, such as clay, to unite with other materials and form a strong coherent mass. The properties known as binding power and plasticity are by no means identical; some clays, for example, have a high binding power but only a moderate plasticity. The binding power of a material is best judged by the amount of medium fine sand which can be added to it without the mixture losing its property of being formed into simple shapes, such as cubes or spheres, which are sufficiently cohesive not to be destroyed by gentle handling.

The precise cause of the binding power of a moulding sand is not fully understood; it appears to depend chiefly on the relative thickness of the colloidal gel, which surrounds the inert particles in the clay or other binder (L. 183). Where the coating is relatively thick it may be spread as a thinner coat over the added non-plastic material, but if the colloidal coating is thin, it cannot be distributed over a larger number of particles without destroying the plasticity of the mixture.

Shrinkage.—Patterns of castings must always be made a trifle larger than the required dimensions of the casting so as to allow for the shrinkage of the mould during the drying; but the conscientious moulder always endeavours to produce moulds with as little shrinkage as possible.

Constancy of volume depends chiefly on

1. The proportion of clay or other binder in the sand (p. 92); an excess of clay causes undue shrinkage.
2. The size of the grains of sand (p. 105).
3. The shape of the grains of sand (p. 104).
4. The proportion of water in the sand (p. 100).
5. The proper preparation of the mould.

The smaller the grains of sand, the lower the proportion of binder and water, and the better the ramming of the mould, the smaller will be the shrinkage, though it can never be wholly eliminated. Grains of such shape and size that they can rapidly be rammed into a dense mass will usually shrink less than those which do not admit of such compacting.

In loam moulding, it is important to select a loam which does not shrink unduly when dry, and the surface of the mould must not be too friable.

Surface and Texture.—The sand which comes into contact with the molten metal must be of such a texture (l. 210) as to give a casting with a smooth or even surface and to facilitate the removal of the moulded article from the sand when cool.

The surface of a mould depends chiefly on

1. The chemical composition of the material forming the face of the mould. It should be highly siliceous, but must not necessarily be a pure sand.
2. The smallness of the grains of sand (p. 105).
3. The grading of the sand (p. 105).
4. The smoothness of the surface of the face of the mould, this being due partly to the sand or other facing material used and partly to the skill of the moulder.

The smaller the grains of sand and the better the grading (p. 105), the smoother can be the face of the mould; the presence of a little plastic clay will also aid in obtaining a smooth finish to the mould. A smooth mould will not necessarily yield a smooth casting; on the contrary, if the face is too dense and impermeable (p. 82), the casting will have a rough face and may be badly "scabbed."

When a facing or blacking is applied to finish the surface of a mould, it should be composed of the smallest available grains, as coarser particles will produce a rough finish.

Chemical Composition.—Too much reliance must not be placed upon the chemical composition of a sand for any particular purpose, though it does serve as a useful guide. Thus, sands of widely different chemical composition may be used satisfactorily for some one purpose, whilst some sands having a similar chemical com-

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position cannot be used to replace each other. In illustration of this H. Ries quotes the following analyses :

	1.	2.	3.	4.
Silica	66.12	70.24	79.36	90.00
Titanic oxide	0.14	0.46	0.34	0.70
Alumina	16.54	16.62	9.36	4.50
Ferric oxide	4.46	3.94	3.18	1.44
Lime	0.40	0.08	0.44	0.10
Magnesia	0.22	0.09	0.27	0.10
Potash	2.67	1.41	2.19	trace
Soda	0.35	0.74	1.54	trace
Combined water	4.90	4.16	2.02	3.04
Moisture	4.15	2.42	0.74	..

Nos. 1 and 2 are very similar in chemical composition; yet No. 1 is a coarse-grained gravelly sand, whilst No. 2 is a fairly plastic loam. On comparing Nos. 3 and 4, the latter might be judged to be the best; yet it is a brick clay, whilst No. 3 is a good moulding sand. In other words, the physical properties are often as important as the chemical composition, and sometimes they are more so.

Moulding sands are usually siliceous sands composed of particles of quartz or other forms of silica together with some clay, oxides of iron, lime, magnesia, and sodium and potassium compounds, and sometimes a little carbonaceous matter. The proportion of silica present varies according to the purpose for which the sand is to be used. McWilliam and Longmuir give the figures shown in Table XXXIII. for the silica content of moulding sands for various purposes :

TABLE XXXIII.—SILICA IN MOULDING SANDS

Type of Casting.	Light Brass.	Light Cast Iron.	Medium Cast Iron.	Heavy Cast Iron.	Steel.
Per cent, silica	78.80	80.82	82.84	84.88	90.99

When the temperature of the metal is very high, and a very refractory sand is required, a highly siliceous sand, containing 95.99 per cent of silica, should be selected. For metals which can be cast at lower temperatures a much smaller percentage of silica will suffice.

Sand to be used in moulding steel from a converter must be highly resistant to heat and should usually contain about 96 per cent of silica. No moulding sand can contain 100 per cent of silica, as it would then be deficient in binding material and so could not be used for moulding.

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Core sands also need to be specially high in silica, as the presence of impurities may cause the sand to be hardened during the casting and so render its removal difficult.

The proportion of silica required generally increases with the temperature of casting, as highly siliceous sands are more refractory than those containing a lower proportion of silica.

As some of the impurities in sand are silicates, the total silica shown by chemical analysis is not an accurate indication of the proportion of free silica present. Felspar, for example, which is frequently present as an impurity in sands, contains about 65 per cent of silica in combination with potash, soda, or lime and alumina. Clay—another compound of silica and alumina—contains 46-70 per cent of silica. Hence, in considering the proportions of silica in a sand it is necessary to make an allowance for that portion of it which may be in combination and is, therefore, to be regarded as part of the impurities in the sand.

The effect of the various silica compounds sometimes present in moulding sands is described in the section on *Mineralogical Composition* (p. 90).

The silica is irregularly distributed throughout the sand, the larger grains containing a larger percentage of silica than the smaller ones. Consequently, if a moulding sand is screened and the particles less than 0.002 in. diameter are removed, the residue will usually be richer in silica. In other words, the impurities in a moulding sand tend to occur chiefly among the smaller particles.

Alumina, when present in moulding sand, is chiefly in the form of clay, felspar, and mica, though other aluminosilicates are sometimes present in very small proportions.

The proportion of alumina which, according to Longmuir, should be present in moulding sands for various purposes is shown in Table XXXIV.

TABLE XXXIV.—ALUMINA PERMISSIBLE IN MOULDING SAND
CORRESPONDING TO CLAY (KAOLIN)

Type of Casting.	Alumina, per cent.	Corresponding to Clay (Kaolin), per cent.
Light brass	12	30
Heavy brass and light iron	10	25
Medium iron	8	20
Heavy iron	6	15
Steel	4½	3

As a general rule, sands with more than 13 per cent of alumina should not be used. Core sands should be low in alumina, that is to say, they should not contain any appreciable amount of clay.

Where there is any appreciable proportion of felspar or other aluminosilicates besides the clay, the proportion of the latter

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cannot be calculated directly from the percentage of alumina, so that care must be taken in estimating the percentage of clay from a chemical analysis. Only the alumina present in the form of clay acts as a binding agent; the other alumina compounds are devoid of binding power.

If the alumina is in the form of felspar or mica much of it will be retained on a 250-mesh sieve, but alumina in the form of clay will pass through the finest sieves, as the particles of clay are extremely small. Hence, most of the alumina in the form of clay can readily be removed by washing the sand, but that in the form of felspar and mica cannot be separated in any simple manner. For further information see the section on *Mineralogical Composition* (p. 90).

Iron oxides are reported in chemical analyses as ferric oxide (Fe_2O_3), but the percentage so shown includes various other iron compounds. The effect of these is described in the section on *Mineralogical Composition*. As iron oxide is a beneficial impurity in a moulding sand, a relatively high percentage is desirable, provided that the iron is in a suitable state of combination. Even in the most refractory moulding sands 2·3 per cent of iron oxide does not appear to be harmful, and for many purposes a higher percentage is desirable. Whilst each case must be considered separately, it will usually be found that the total proportion of iron, expressed as ferric oxide, should not exceed 6 per cent in a moulding sand to be used for casting steel; in one for casting other metals, it may sometimes be as high as 11 or 12 per cent, as a ferruginous bond has very desirable properties. Further information on the use of iron compounds as bonds will be found in the section on *Bonds* (p. 115).

Lime does not occur in the free state in moulding sands, but is chiefly present in the form of calcium carbonate (as limestone and chalk) and of various calcium silicates, as well as calcium aluminosilicates analogous to and including lime-felspar; the most important of these calcium compounds are described in Vol. I, pp. 190-193. In casting steel and other metals of very high melting point, the moulding sand should not contain more than 0·5 per cent of lime, that for casting iron not more than 1·5 per cent of lime, but for casting brass 2·5 per cent of lime may be present; and when casting metals of still lower melting point, 4·6 per cent of lime does not appear to be detrimental. Whilst these figures are of general application, sands have been used successfully containing as much as 12 per cent of lime, though such sands are not to be recommended.

Magnesia does not occur as such in moulding sands, but in the form of mica and other complex magnesium silicates. As magnesium compounds act as fluxes and reduce the refractoriness of the sand, they should be completely absent when possible, and, at least in the better qualities of moulding sand, the total magnesia present should not exceed 0·5 per cent (see p. 90).

Alkalies.—potassium and sodium compounds—may be present in moulding sands either as insoluble aluminosilicates, such as felspar, mica, etc. (I. 184), or as soluble chlorides or sulphates, the latter being conveniently considered under the term "soluble salts." The total percentage of potash and soda shown by analysis should be as low as possible—preferably well below 1 per cent, as these substances greatly reduce the refractoriness of the sand and so tend to cause "burning on" and other defects in the castings.

The Bunter sands are relatively rich in potash, which occurs chiefly in the form of felspar, but partly as mica, about 15 per cent of these two minerals being present in some of these sands (see Table XXXVI. p. 91). According to Boswell, the best moulding sands should contain 0.5 to 0.7 per cent of soda and potash, and in no case should more than 1 per cent be present, if the sands are to be used for casting steel and other metals of high melting point. For iron and most non-ferrous metals the proportion of alkalies present is usually of minor importance, as the felspar and mica in which they are contained do not begin to fuse at any temperature below 1200° C.

The *loss on ignition* in a dried moulding sand is usually so small that it need not be considered. When it exceeds 1 per cent it indicates the presence either of minerals, such as clay, containing the elements of water in combination, or of organic matter. For further information see pp. 90-100. The effect of moisture in moulding sands is discussed on p. 100 later.

Moisture.—The moisture in a sand should not exceed about 5 per cent, or various difficulties may arise (see *Mineralogical Composition*, p. 100).

The "total impurities" is sometimes estimated by a method recommended by Le Chatelier, which consists in heating a weighed quantity of the sand with sulphuric and hydrofluoric acids, and weighing the residue left after gentle calcination. This treatment removes the silica and converts the metallic oxides into sulphates and fluorides. The method affords only a rough means of estimating the impurities present, because, as the combined silica has been removed, the weight of the residue is less than that of the total impurities. Nevertheless, the method is useful as a means of controlling the quality of the sand.

Table XXXV. shows the composition of various natural British and foreign moulding sands. Some of these sands vary considerably in composition from time to time, the purer ones being much more constant than the rest. As the analyses are typical, the results are only shown to one decimal place.

Additional analyses of these and other British and foreign moulding sands are given in Boswell's *Memoirs*.¹

¹ *A Memoir on British Resources of Refractory Sands*, by P. G. H. Boswell (Taylor & Francis, London), and *A Comparison of British and American Foundry Practice*, by P. G. H. Boswell (University Press of Liverpool, Ltd., Liverpool).

TABLE XXXV.—TYPICAL ANALYSES OF MOULDING SANDS

	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Potash and Soda.	Loss on ignition.
<i>British</i>							
Anglesea	99.4	0.2	*	0.1	*	*	0.2
South Cave red	79.7	6.5	8.9	1.2	0.3	0.9	2.5
" yellow	93.0	3.3	1.2	0.4	0.1	1.5	0.5
Clyde Valley	88.9	5.2	3.4	1.0	0.9	0.1	0.5
Glenboig ganister	94.8	3.2	0.4	0.2	0.2	0.8	0.4
Sheffield ganister	90.2	4.0	2.6	0.4	*	0.4	2.3
Aylesbury	98.6	0.5	*	0.2	0.1	*	0.4
Leighton Buzzard	99.4	0.2	0.3	*	*	*	0.1
Kings Lynn	98.6	0.9	0.2	0.1	*	*	0.2
Charlton	95.0	2.3	0.5	0.2	*	1.1	0.9
Bawtrey, near Doncaster	92.9	3.0	1.0	0.3	0.2	2.0	0.4
Huttons Ambo, Yorks. . .	96.6	1.5	0.3	0.1	0.2	0.6	0.7
St. Erth (Cornish red) . .	86.5	4.5	2.8	0.5	0.5	3.4	1.8
Erith	86.8	5.6	2.5	0.4	0.8	2.4	1.5
Belfast	75.2	8.3	1.6	4.2	1.3	4.1	5.3
Birmingham	79.0	11.8	1.8	3.0	0.6	2.1	1.7
Kidderminster	85.7	6.3	1.4	0.7	0.5	3.7	1.7
Mansfield red	88.4	5.1	1.3	0.2	0.6	2.8	1.6
Stourbridge red	84.5	4.7	5.4	0.7	0.5	3.1	1.1
Wolverhampton red	86.4	6.4	1.2	0.3	0.4	3.6	1.7
Woolwich (Thames sand)	93.8	3.4	0.5	0.2	*	1.0	1.1
Worksop	88.6	6.8	0.6	0.2	0.2	1.5	2.1
<i>Foreign—</i>							
Belgian red	88.4	4.7	5.2	0.2	0.1	0.9	0.4
" yellow	87.5	5.1	3.1	0.3	0.4	0.7	2.9
Fontainebleau	99.5	0.2	*	0.1	*	*	0.2
French (red)	90.1	3.0	2.5	0.2	0.3	1.1	2.8
Ottawa (U.S.A.)	99.4	0.3	*	0.1	0.1	*	*

* Indicates that less than 0.1 per cent is present.

† Including carbon dioxide.

Mineralogical Composition.—Numerous minerals are present in moulding sands, but most of them are in such small proportions that they may be neglected. The following minerals are, on the contrary, of great importance, as the essential and characteristic properties of these sands are largely due to them.

The proportion of some of these minerals may be determined by microscopical examination, aided by the use of heavy liquids (I. 257) and by the analysis of the products obtained by mechanical analysis (I. 246), but the more usual course is to calculate the mineralogical composition from the results of a chemical analysis, as described in Vol. I. p. 240.

The calculation of the mineralogical composition is unreliable when applied to sand which has been made into a mould and so used, as some of the clay in it will then have been decomposed and will have lost its binding properties. Hence, it is always desirable to compare the mineralogical composition with those of a mechanical

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analysis. The typical (calculated) mineralogical composition of various moulding sands is shown in Table XXXVI.

TABLE XXXVI.—MINERALOGICAL COMPOSITION OF TYPICAL MOULDING SANDS.

	Quartz.	Felspathic Matter.	Clay.†	Limontite.§
<i>British—</i>				
Anglesea	98.7	1.0	..	*
South Cave red	66.6	15.0	9.5	8.9
" yellow	83.3	12.6	2.9	1.2
Clyde Valley	77.0	12.5	7.5	4.0
Clyde ‡	80.2	12.8	7.0	..
Glenboig ganister	87.0	7.5	5.0	0.5
Sheffield ganister	83.8	5.0	8.0	3.0
Aylesbury	97.0	1.9	0.7	*
Leighton Buzzard	99.2	*	0.5	0.3
Kings Lynn	97.2	0.6	2.0	0.2
Charlton	88.6	8.1	2.3	0.6
Bawtrey, near Doncaster	82.2	15.6	0.7	1.2
Huttons Ambo, Yorkshire	92.9	5.7	1.1	0.3
St. Erth (Cornish red)	69.1	27.5	..	3.3
Erith	70.4	22.5	4.0	3.0
Erith ‡	74.1	11.4	14.5	..
Belfast	50.6	33.8	5.5	1.9
Birmingham	50.5	35.6	12.1	1.8
Kidderminster	66.5	28.1	3.1	3.6
Kidderminster ‡	79.0	13.3	7.7	..
Mansfield red	73.3	22.5	2.7	1.5
Mansfield ‡	73.4	22.4	4.2	..
Stourbridge red	66.7	27.0	*	6.3
Stourbridge ‡	66.0	23.5	10.5	..
Wolverhampton red	67.4	27.0	3.7	3.4
Woolwich (Thames sand)	80.4	18.8	*	0.6
Worksop	75.5	11.9	11.7	0.7
Worksop ‡	74.0	12.9	12.6	..
<i>Foreign—</i>				
Belgian red	77.6	8.3	7.5	6.1
" yellow	78.6	8.7	9.0	3.6
Fontainebleau	99.1	0.6	0.2	*
French red	83.2	10.0	3.0	2.9
Ottawa (U.S.A.)	98.5	1.2	0.2	*
Brandeburg ‡	87.3	2.5	10.2	..
Hanover ‡	86.1	6.4	7.5	..
American "average" ‡	65.5	12.7	21.8	..
American "ideal" ‡	84.0	2.5	13.5	..

* Indicates less than 0.1 per cent present.

† Assumed to have the composition—46 per cent silica, 40 per cent alumina, and 14 per cent water, etc.

‡ Figures published by Moldenke showing the great variations in some clays from the same locality.

§ The whole of the iron compounds are assumed to exist as limonite (I. 189) and also contain 7.4 per cent of calcium carbonate.

NOTE.—The percentages of felspathic matter and clay obtained by calculation are often far from reliable, as a small difference in the percentage of lime, magnesia, or alkalies makes a large difference in the felspathic matter. The results of such a calculation must therefore be received with caution.

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As shown in Table XXXVI. the percentage of quartz or free silica may be as low as 50, or as high as 95 per cent. The clay may vary from practically *nil* to as much as 40 per cent, whilst the fluxes (consisting chiefly of felspar, decomposed and undecomposed mica, etc.) may vary very considerably, as much as 30 per cent being present in some moulding sands which give quite satisfactory results in the foundry, and the "limonite" varies from *nil* to 12 per cent.

There is no standard composition for moulding sands, and though the American "ideal" has been stated by Moldenke to be that shown in Table XXXVI., recent investigations by Boswell show wide variations both from the ideal and the average figures given by Moldenke. The moulding sands now in general use in the United States are more siliceous and contain less clay and iron oxides than those used in this country; consequently, they have to be "prepared" by the incorporation of fireclay or other bond (p. 115). American moulding sands with a natural bond are only found in New Jersey, but, according to Boswell, these sands contain much less alumina and iron oxide than the corresponding British sands, and molasses, flour, dextrin, or some other bond is usually added. The mineralogical composition of the moulding sands used in Great Britain varies so greatly, according to the purposes for which they are used, that no average figure would be of any value.

Turning to the important minerals present in the sands, the following observations may be made:

Quartz is the chief and most important mineral present; yet a sand which consisted of pure quartz would be useless for moulding, as it would lack plasticity and cohesion. The percentage of quartz should therefore be as high as possible, consistent with the essential physical properties of the sand. The effect of the size and shape of the particles of quartz on the properties of the sand is described later.

Clay is nearly always present in moulding sands and may be regarded as a necessary constituent, because it binds together the particles of sand and so forms a strong mass which will resist the abrasive action of the molten metal. For this reason the strength of a moulding sand depends chiefly, though not wholly, on the proportion and nature of the clay present (see p. 93).

Many sands contain naturally sufficient clay to render the material quite satisfactory for moulding; thus, loams are sandy clays or clayey sands, some of which are among the best moulding sands. In some cases an artificial mixture of fireclay and alluvial sand is employed, in others several natural sands are mixed together in order to produce a material possessing the desired properties. Some sands which are not sufficiently cohesive or plastic are improved by the addition of a suitable proportion of water containing clay in suspension.

In considering the effect of clay on the moulding properties of a sand it is necessary to pay attention to (i.) the purity or other-

wise of the clay, (ii.) its plasticity, (iii.) its binding power, and (iv.) the proportion of clay present.

The *composition of the clay* is important, because some impurities, in it may lower the refractoriness of the sand and cause the latter to adhere to the metal, and as most of the impurities are non-plastic they reduce the binding power of the clay. Apart from any iron oxide (ferric oxide) which may be a constituent of the clay, the clay present in a moulding sand (no matter whether it is present naturally or introduced artificially) should be as pure as possible. The presence of more than a very small percentage of soda, potash, lime, and magnesia is objectionable, as all these substances reduce the heat resistance of the sand and tend to make it adhere to the metal, as well as closing the pores in the mould and so preventing the normal escape of air and gases. A considerable percentage of very fine silica flour ("rock-dust"), which occurs in some clays, is also objectionable, as such material has no binding power (and therefore reduces the binding power of the clay) and also increases the proportion of undesirably small grains of silica.

It is sometimes stated that the clay occurring in or to be added to a moulding sand should "not be too pure," as it would lack binding power; this is a mistake, as the binding power is a physical property of the clay and has nothing to do with the impurities present in it. On the contrary, it is merely a coincidence that some of the most plastic clays are far from pure. Where the clay occurs naturally mixed with the sand little can be done to effect its purification, as any treatment which removes the impurities in the clay will also separate the clay from the sand. When artificial mixtures of clay and sand are used a sufficiently pure clay can generally be obtained.

In examining a natural moulding sand it is important to separate the clay present by sieves (l. 246) or elutriation (l. 252) and to investigate it thoroughly, as many defects in castings which are attributed to the moulding sand have their origin in the clayey portion of the sand (see *Artificial Bonds*, p. 114).

The *plasticity* of a clay is not of great importance as regards its usefulness in a moulding sand, but it is a valuable indirect indication, since most plastic clays possess a high binding power.

The *binding power* of the clay in a moulding sand is probably its most important characteristic, as this property determines the cohesion or plasticity of the sand as a whole. The greater the binding power of the clay, the smaller will be the proportion of clay required in order to produce a good moulding sand. The binding power of a clay is best determined as described in Vol. I. p. 266.

When any clay has been treated throughout to a temperature of 500° C. it is decomposed and, consequently, its binding power is destroyed. No treatment commercially practicable can then restore the binding power to the clay. If, on the contrary, heating has merely been sufficient to dry the clay, but not to decompose

it, or only to decompose it to a small extent, it will regain the greater part of its binding power when mixed with a suitable proportion (usually about 20 per cent) of water. The recovery of binding power is reduced as the temperature of 500° C. is approached, because clays decompose at all temperatures above 100° C., and therefore cannot regain the whole of their binding power; after heating for a sufficient time to 500° C. or above, however, none of this power can be restored. The fact that any restoration whatever is possible is due solely to some of the clay not having been decomposed by the heat. This is a result of the very low heat conductivity of clay and sand, which prevents the clay from being decomposed very rapidly, except at very high temperatures.

The decomposition of the clay when heated is also increased by the presence of lime, magnesia, potash, and soda, and by using some of their compounds which combine with the clay, forming non-plastic aluminosilicates. This is one reason why a moulding sand should be as free as possible from such fluxes.

The *percentage of clay* permissible in a moulding sand varies with the binding power of the clay and the nature of the metal to be cast, so that no very definite figure can be given. As the only purpose of the clay is to bind the particles of sand together sufficiently well to give the mould the desired strength, any additional clay is objectionable; it is not merely useless, it reduces the permeability of the mould and so tends to cause cracks, and in the case of cores it hardens the sand so much as to make the removal of the cores very difficult, as they do not break readily. Clay also increases the shrinkage of the moulds and so tends to produce distorted or undersized castings. Consequently the proportion of clay present in or added to the sand should be as low as possible, consistent with the production of the requisite cohesion or plasticity of the sand. The exact properties can only be found by trial (see the test for binding power of a moulding sand in Vol. I. p. 266).

The proportion of clay in natural moulding sands varies according to their formation, the finer sands usually containing more clay than the coarser ones. Much of the clay can be removed by separating the smaller particles by means of a sieve, though there is always some risk of spoiling the sand by taking out too large a proportion of the clay. The proportion of clay required in a moulding sand depends very largely on the surface area of the sand, i.e. on the total area of the surface of all the individual grains (I. 211). This is important, because the clay should, theoretically, cover each grain of sand with a film of just sufficient thickness to enable other grains to adhere to it. Consequently, if the same proportion of clay is present in two sands, one of which consists of very large grains, and so has a small surface area, whilst the other consists of very small grains, and so has a large surface area, the sands will behave quite differently. The finer sand will require

the addition of more clay in order that it may be as "strong" as the coarser sand. Alternatively, if a sufficient quantity of clay is present in the finer sand, the coarser one will contain an excess of clay. In other words, with a definite amount of bond present in a sand, the coarser the grains the stronger will be the bond within ordinary limits; in an exceptionally coarse sand the reduced contact area between the particles produces larger spaces between the grains, and consequently enough additional clay to fill these voids is required.

The amount of clay or bond divided by the surface area of the sand gives a useful figure for comparing sands: it is termed the "bond density" and, according to Hanley and Simonds, is a more reliable guide to the relative strength of sands than any other single property possessed by them.

The proportions of clay permissible in various kinds of moulding sands are roughly as follows: For light castings, a sand containing only a small proportion of clay should be used, but for heavier castings the proportion of clay present should be greater, as heavy castings require a stronger sand. Sands used for dry sand work must usually contain a greater proportion of clay than those used for green sand moulds, so as to allow the sand after drying to be firm and stable.

Floor or backing sands require a moderate proportion of clay in their composition, as they must be fairly strong; an excess, however, is undesirable, as such sands must be sufficiently permeable to allow the air and gases to pass freely through the mould. The average proportion of clay which gives the best results in a floor sand is about 6 per cent; larger proportions are used where a more adhesive material is required, though an organic binder is then often added instead of more clay, as such a binder does not harden the mould when in use. Sands used for loam moulding without a pattern should contain a moderate proportion of clay, but an excess must be avoided or the sand will contract unduly and will not be sufficiently porous. More clay is required than in sand for box-moulding, as the loam must be hard enough to be rubbed gently whilst in the dry state without being too friable. A good test for a loam is that, when dried in an oven, it should bake hard and strong and not show undue shrinkage. A useful composition is 60 per cent of quartz and 40 per cent of grains less than 0.007 in. diameter, containing the silt, clay, and fluxes. The face of the mould should usually contain a high proportion of sand so as to resist the intense heat of the molten metal.

The high percentage of clay in many loams closes the pores of the material and makes it unsuitable for moulding purposes, unless certain other materials such as sawdust, horse-dung, straw-chaff, plasterer's hair, bran, or chopped tow are added to form channels which allow the free escape of the air and gases generated at the time of casting. Good natural loams are not usually abundant, so that it is generally necessary to make them artificially.

For the siliceous part of artificial loams, river sand or crushed sand-rocks are very satisfactory, sea sand being sometimes used, though it is less desirable, as it tends to introduce soluble salts into the material. In general, about 1 part of clay is used to 4-6 parts of sand. The actual properties of sand and clay in loams for metal casting vary considerably and are mostly regarded as secrets. Each foundryman has certain mixtures of loam and sand which he prefers to all others, and, in some cases, he compounds his own loams by mixing clay and sand in the requisite proportions, with or without the addition of horse-dung, etc.

Core sands should not contain more clay than is absolutely essential, as the temperature to which they are heated is very great and the clay becomes baked and hard, making the cores very difficult to remove.

Raw clay is undesirable in *parting sands*, as the presence in them of a binder is not only unnecessary but harmful, and may cause the various proportions of the mould to adhere instead of keeping them separate. A parting sand should consist wholly of small non-plastic particles of sand, but a little clay which has been thoroughly burned (p. 93) will do no harm, as it has lost its plasticity. Parting sands usually consist either of a clean sea or river sand containing no appreciable amount of clay, burnt sand, in which all the clay has been hardened and rendered non-plastic, brick-dust, which consists of burnt clay, or cinder-dust.

Old or used sands are deficient in binding power on account of some of the clay originally present having been decomposed by the heated metal when in use. Such sands may, in some cases, be "restored" by screening and then mixing them with a sufficient proportion of new strong sand (*i.e.* one containing an excess of clay) or with a little lean clay; the plasticity, cohesiveness, and strength of the product will depend on the amount of undecomposed clay left in the used sand. Many facing sands used in foundries consist of 25 to 75 per cent of old sand mixed with new strong sand. New sand is preferable for brass and all non-ferrous alloys, 1-2 parts of pea- or bean-meal or flour being mixed with each bushel of sand.

In addition to the use of clay in sands as a binding material, burned clay in the form of old fire-bricks and crucibles is sometimes added as an opening material, and also to secure a highly refractory sand. This is especially the case in the "Compos" used as facing sands in casting steel (see p. 79).

Fluxing Minerals or Fluxes are those which combine with silica or any other constituents in the sand and form fusible compounds, some of which melt when the molten metal is in the mould. This is very objectionable, as the fused material may adhere to the metal (see "burning on," p. 80) or it may flow and fill some of the pores in the sand, and by preventing the proper escape of the air and gases, it may cause "seabs" (p. 80) and other defects. When a sand containing partially fused material is allowed to cool, it will be found to contain hard masses of material which cannot

be used as sand unless they are re-ground. Even after such treatment the re-use of such sand is undesirable, as the proportion of fusible material increases and in a short time the sand is rendered quite useless.

The effect of fluxes on any given moulding sand depends on the conditions under which the sand is used. Thus (a) if the temperature attained is below that at which the flux forms a fused compound, little or no harm will be done; but once fusion occurs, the defects previously mentioned may be produced. Consequently, for metals cast at temperatures above 1200°C ., the moulding sand should be as free as possible from fluxes and contain not more than 2-3 per cent of magnesia, lime, potash, and soda: in the best moulding sands, the total proportion of these oxides will not exceed 1.5 per cent. (b) If the proportion of flux is very small, its effects may be inappreciable. (c) The nature of the casting to be produced also influences the effect of a flux.

When a casting is thin it cools rapidly, and the mould is not subjected to a prolonged heating, so that a considerable proportion of fluxes may be present without detriment, but with heavy castings the mould is kept at a high temperature for a considerable time, and any fluxes present are sure to react with the silica and form a fused product; for such castings, therefore, it is important that the proportion of fluxes should be as low as possible. The most important fluxes in moulding sands are soda, potash, lime and magnesia and their compounds; these substances occur chiefly in the form of felspar, mica, calcium carbonate (chalk and limestone), and various "soluble salts" (p. 98). The proportion of fluxes naturally present in moulding sands varies considerably, but the smaller particles ("fine sands") usually contain the larger proportion of fluxes, and so should be absent or removed as far as possible when refractory moulding sands are required.

Limestone, chalk, or other forms of calcium carbonate are objectionable in moulding sands if any part of them is likely to be raised to a temperature of 750°C ., as at this temperature calcium carbonate evolves carbon dioxide gas, which gives the casting a rough or pitted surface. At still higher temperatures the resultant lime combines with the sand and fuses, forming a very fluid slag which flows into the interstices and blocks them, thus reducing the permeability of the sand. Calcium carbonate is very undesirable in parting sand, as it has the opposite effect to that which is desired and increases instead of reducing the adhesion of the sand.

In core sands, calcium carbonate increases the amount of oil required for binding, and makes the cores so hard that they are difficult to remove after use.

Magnesium compounds occur to so small an extent in moulding sands and are so difficult to identify therein, that they may without serious error be regarded as having the same properties as the corresponding calcium minerals, of which limestone, chalk, and

Organic Matter, when naturally present in a sand, is usually of vegetable origin (I. 200). It may also be introduced accidentally into the sand as a result of bad working, by which some of the overburden may have been mixed with the sand, or of water carrying carbonaceous matter in solution or suspension percolating through the bed (I. 200). Organic vegetable matter is usually harmful, and, as a general rule, sands containing more than 1 per cent should be avoided, especially if they are to be used for cores.

Carbonaceous matter, including some organic matter, is frequently added to moulding sands to increase their permeability and to produce a smoother face on the casting. (See *Preparation of Moulding Sands*, p. 113.)

Water, whilst not often regarded as a mineral, may conveniently be considered in this section. The presence of water (moisture) in a moulding sand is sometimes a serious disadvantage, which can only be avoided by carefully drying the sand before use. A perfectly dry and moisture-free sand is too friable to be used; a small proportion of moisture (unless oil is used) must always be present to develop sufficient plasticity in the sand to enable it to be made into the desired shape. Beyond this small proportion of water (which seldom exceeds 5 per cent of the weight of the sand, unless the latter is very fine and, having a larger surface area, requires more water) any excess is harmful, as it reduces the strength of the mould and also interferes with the permeability of the mould if the green sand method (p. 76) or loam moulding (p. 76) is used. Hence, if a moulding sand contains more than about 5 per cent of moisture, as is frequently the case, it should be dried until its moisture-content is reduced to the amount just mentioned. Some of the Bunter sands, for example, contain 13 per cent or more of water, and should be dried until they contain about 4 per cent, in order to secure the best results.

A rough, yet convenient, test for a serious excess of water in a moulding sand is to press a sample into the shape of a ball in the hand. If any sand adheres to the skin the material is probably too wet to be satisfactory. It is much better to have the percentage of moisture determined in a proper manner (I. 238).

Unfortunately, many foundrymen are very careless with regard to the amount of moisture in moulding sands, in spite of the fact that it has such a profound influence on the strength of the moulds. This is well shown by Table XXXVII., due to F. A. Hayes, which shows the result of determinations of moisture on several days in the sand from different floors of the same foundry, all the men on which were using the same sand for the same general class of work.

It will be seen that there was a difference of 3.77 per cent in the moisture-content of Pile No. 2 on two different days, and smaller variations in the other piles. Although these differences might be explained by the fact that different moulders ram the sand to different extents and, therefore, require sands of different dampness, yet this does not account for the variations in any one pile. As it

TABLE XXXVII.—VARIATIONS OF MOISTURE IN SANDS

Pile Numbers .	1	2	3	4	5	6	7	8
First day . .	4.79	4.14	5.18	5.58	5.63	6.11	6.45	5.13
Fifth day . .	5.41	7.14	6.07	5.93	4.82	5.94	6.46	6.78
Tenth day . .	4.32	7.91	6.47	7.06	..	..	..	..

is essential, especially in green sand moulding, that the moisture should be uniformly distributed through the sand and kept as constant as possible, there is considerable scope for better control and more efficient mixing or tempering of the sand in some foundries, even when a single sand is used.

The chief effects of an excess of water in a moulding sand are :

1. Moulds made of wet sand are weaker than those made of sand containing only 4.5 per cent of moisture. The effect of water on the crushing strength of moulding sands is shown in Table XXXVIII., due to Moldenke.

TABLE XXXVIII.—CRUSHING STRENGTH OF MOULDING SANDS
(lb. per sq. in.)

Kind of Sand.	No. of Tests.	5 per cent Water.	7½ per cent Water.	10 per cent Water.	Dry.
Fine	18	3.11	2.97	2.48	7.82
Medium . . .	10	4.03	3.28	2.38	13.70
Coarse . . .	48	4.82	3.43	3.68	14.29
Specially strong .	..	3.57	2.76	3.32	60.30

The remarkable increase, after drying, in the strength of the last sand in Table XXXVIII. should be noted.

The amount of water required to develop the full strength of a sand varies according to the moisture in the sand, the proportion of voids, the total surface area of the grains (I. 211), and the amount of clay present. The maximum strength will be obtained by adding water up to a certain limit, but an increase beyond that amount will separate the grains unduly and will decrease the porosity.

Table XXXIX., due to A. L. Curtis, shows the proportions of water required to produce the maximum strength in the sands investigated by him.

In each case the percentage of water required is quite small, and justifies the recommendation previously made that the proportion

TABLE XXXIX.—WATER REQUIRED TO DEVELOP MAXIMUM STRENGTH

Source of Sand.	Amount of Water.
Staffordshire	6 per cent.
Worsop	5 "
Roe Park, Cheshire	4 "
Runcorn	3.5 "
Stourport	4 "
Devonshire	5 "
Birmingham	3.8 "
Cumberland	5 "

of water in a moulding sand should not usually exceed 4.5 per cent.

2. Moulds made of very wet sand shrink when dried, and are liable to produce undersized or distorted castings.

3. Moulds made from wet sands are less permeable than those made of sands containing only 4.5 per cent of moisture, and if such moulds are dried before use the shrinkage may have serious results (see 2, above).

4. Moulds made with wet sands and afterwards imperfectly dried are liable to be dangerous to the workmen, as well as certain to produce defective castings. It is comparatively easy to dry small moulds, but the larger ones used for heavy castings can only be dried superficially; when this is the case, the interior of the mass of sand remains damp. When the molten metal is poured into the mould, the moisture present in the sand is converted into steam and should escape, along with any other gases, through the pore-spaces and vents in the mould. The effect of any surplus amount of water is not serious, provided the mould is sufficiently porous to allow all the moisture and gases to escape rapidly, but, unfortunately, moulds containing moisture are not so porous as those made from dry sand, as a film of water surrounds each grain of sand and fills up part of the voids between them, thus giving a smaller effective pore-space. They are also less permeable, as this water greatly increases the resistance offered by the mould to the passage of steam or gases.

If the proportion of moisture in the mould is at all considerable, its conversion into steam may cause the mould to shrink, as the particles of sand go closer together after the removal of the water. This is not serious if the proportion of moisture is sufficiently low, but if it is high, the mould may be deformed and so produce a defective casting or an explosion may occur. Moldenke tested the permeability of the three moulding sands containing varying proportions of water, by determining the number of seconds necessary to drive 1 gallon of air through a $\frac{1}{4}$ in. orifice on one side of a block of the sand 1 in. thick, the other side being open to the atmosphere. The results are shown in Table XL.

TABLE XL.—PERMEABILITY OF MOULDS

Kind of Sand.	No. of Tests.	Seconds required for 1 Gallon of Water to pass through 1 in. Block.			
		6 per cent Water.	7½ per cent Water.	10 per cent Water.	Dry Sand.
Fine . . .	18	1.65	1.75	2.71	1.29
Medium . .	10	0.68	0.85	1.10	0.93
Coarse. . .	48	0.89	1.34	1.79	0.97

It will be seen that the moulds containing a small proportion of water have a greater permeability than those made of dry sand, except in the case of the fine sand, when it is most permeable in the dry state.

A further defect caused by the use of a mould in which the sand is too wet is that, when the molten iron comes into contact with the sand, scabs occur because the gas and steam generated by the heat cannot escape sufficiently rapidly through the pores in the mould, but, on the contrary, push out a portion of the drier sand to the molten iron, so that rough lumps are left on the casting. During the time the scabbing is taking place the gases follow the line of least resistance by passing through the molten iron into the runner gates and risers with a series of puffs and blows, which are actually small explosions.

5. Wet sand will not mix well with some binders, so that when the latter are used the sand must be thoroughly dried before being mixed.

6. Different metals require different amounts of moisture in the mould at the time of casting. With aluminium, for example, the sand should be as dry as possible, as it is most important to avoid a large evolution of gas. In iron-founding this is not so important, as molten iron is heavy and dense and the gases take the line of least resistance, which invariably lies through the sand. Aluminium is so much lighter and less dense that it has only one-third of the resistance to the gases, with the result that of two casts made under identical conditions an iron casting might be perfectly sound and the aluminium one "blown," owing to the smaller resistance of the molten aluminium. If it is necessary to use a slightly damp mould for aluminium, it should be given a more open and permeable texture than usual by ramming it as lightly as possible and paying special attention to the use of a sand with a larger proportion of voids, so as to facilitate the passage of the gases through the sand.

7. The cost of drying the moulds is much greater than that of drying the sand, so that the use of wet sand, which necessitates

further drying of the moulds, is extravagant both in fuel and labour. It is particularly necessary to dry the sand to be used for making cores.

8. To avoid using a wet sand, some moulders go to the other extreme and dry the mould so thoroughly that all moisture is driven out and the clay in the moulding sand is partially baked. This creates other difficulties in casting, particularly with such a metal as aluminium alloys, which have a high shrinkage and a pasty condition at high temperatures. Over-dried moulds would, unless speedily cased after casting, cause the casting to crack, by offering a resistance at a time when the metal was in its weakest phase.

Some sands, when dried gently and without overheating, form a compact and coherent yet porous mass; others form friable masses when dried, and so cannot be used in this state unless they have previously been mixed with a special binder. Mansfield, Staffordshire, and Erith sands may be used as dry facing sands either alone or mixed with horse-dung. Rock sands contain practically no moisture, and are generally used for dry sand work, an added binder being generally necessary. Various mixtures of clayey sands (loam) and other sands are also often used as dry sands.

Dry sands are preferable for casting brass, as when thoroughly dry they may be tamped harder than when in the green state. When green-sand moulds are used for brass they should be much drier than those used for casting iron.

Shape of Sand Grains.—The question as to what is the best shape for the grains in a moulding sand has frequently been discussed, but no general agreement thereon has yet been reached. In investigating this problem there are three factors to be considered:

- (a) Which shape of grain will produce a mass with the maximum strength?
- (b) Which shape of grain will produce the requisite porosity and permeability in the mould?
- (c) Which shape of grain will produce the desired smoothness on the surface of the casting?

To obtain the maximum strength the grains should be sharply angular and interlock so as not to be moved when in contact with the molten metal. Interlocking grains will not produce the maximum porosity, as sharp angular grains are inferior in this respect to rounded grains, which have no interlocking power. Rounded grains also give a more permeable mass for the same pore-space than angular grains, on account of the greater smoothness of their surfaces and consequent smaller frictional resistance to the passage of gases. It is therefore necessary to compromise, and where strength and resistance to abrasion are necessary (as in facing sands) a sharp angular sand must be employed, whilst where strength is not of such great importance a more rounded sand

may be used so as to secure a greater porosity. A great advantage possessed by round grains is that they will still give a porous mass, however hard they are rammed, whereas sharp grains become interlocked and so reduce the porosity. Moreover, when a sand consisting of sharp grains is rammed, those nearest the set of the blows will be closely interlocked, but those farther away will not be appreciably affected. Consequently, the mould will not be homogeneous and the casting may swell at those parts where the sand is too open. This defect may be partly avoided by ramming in thin layers at a time, but with rounded grains this is not necessary, as the pressure is transmitted from grain to grain and none of the particles are packed too lightly. The great popularity of some well-known foundry sands, such as the Belgian yellow sand, is largely due to the fact that they consist chiefly of rounded grains and so are easy to use. For this reason some foundrymen always form the backing of the mould with a sand consisting of rounded grains.

Some *core sands* have rounded and others have sharp grains; the latter form a strong mass, which is often necessary for core work. Rock sands are very desirable for making cores, both on account of their sharpness and also on account of their purity (p. 87). Granite sands are angular in grain, and when they contain or are mixed with a small quantity of clay, they form a very suitable core sand where angular grains are required. On the other hand, the most effective venting of the mould is obtained with a round-grained sand, so that each moulder must decide which kind of grain would be the best for the particular work in hand; thus, where specially good venting is necessary, as in small cores, rounded grained sands must sometimes be employed in order to assist the gases to escape. Sea sand in conjunction with oil (p. 117) is often used for cores.

Parting sands should preferably have round grains, as they are used to prevent the various portions of the mould from adhering to each other. A used or burnt facing sand is generally very satisfactory for this purpose.

Sizes of Sand Grains.—The size of the grains of sand in a moulding composition is important, as on it depends the ability of the sand to get rid of gases evolved during and after casting, and therefore to prevent the formation of blow-holes in the metal.

To secure a maximum permeability, the grains should be of uniform size, grading (p. 35) being undesirable, as a fine sand having grains of approximately uniform size has a greater permeability than one containing grains of various sizes, the smaller ones filling up the interstices between the larger grains and so decreasing the total proportion of voids. For this reason, the proportion of silt and very fine sand should be as low as possible, preferably not more than about 10 per cent. Provided they are not so large as to produce a very rough surface on the casting, the size of the individual grains is not of much importance in a moulding sand,

as the percentage of voids is approximately the same whatever the size of the individual particles, provided they are of all the same size. Thus, a sand consisting entirely of grains of about 40-mesh will have the same percentage of voids as one consisting of grains all of which are about 10-mesh, but fine sands usually have a greater pore-space than coarse sands, as shown in Table XLI.

TABLE XLI. - RELATION OF POROSITY TO FINENESS (H. Ries)

Sand.	Average Fineness.	Specific Gravity.	Per cent Pore-space.
1	174	2.50	42.45
2	163	2.72	44.70
3	131	2.62	40.43
4	103	2.57	43.20
5	88	2.62	38.00
6	70	2.73	32.91
7	63	2.55	39.52
8	54	2.61	38.83

The figures mentioned are only applicable to perfectly clean sands; in some instances, the smaller particles may have a smaller porosity than the larger grains because of the effect of the clay or other natural bond present in the sand.

As explained on p. 81, the porosity of a sand is not always a reliable guide to its permeability, as the escaping gases will pass more readily through large pores than through small ones, so that a coarse sand has a greater permeability though it may only have the same porosity as a finer one.

The chief disadvantage of a uniformly-sized sand is that it does not give so smooth a surface to the casting as one consisting of irregular-sized grains, but the disadvantage of the latter is its lower permeability. For large or rough castings which have afterwards to be machined or where a rough surface is not important, a coarse sand is quite satisfactory, but for smaller or more highly finished castings it is desirable to use fine-grained sands. The most desirable moulding sands contain as high a proportion of fairly coarse particles as the surface desired on the casting will permit, together with a sufficient quantity of fine particles of clay or other bond; the proportion of intermediate-sized material should be as small as possible. The nature of the metal must, however, be considered; thus, coarse sands cannot be used for casting aluminium, as they give a rough matte appearance to the surface of the castings; fine sands must therefore be used with this metal, and the mould must be tamped very lightly so as to ensure the ample permeability necessary in casting aluminium.

An excess of fine silt or dust should not be present in moulding sands, as it renders the sand weak, besides reducing its porosity. For general purposes, moulding sands should leave little residue

on a 30-mesh sieve; that is, few grains should be larger than 0.02 in. diameter, 70 per cent or more of the grains should be between 0.01 in. and 0.02 in. diameter, so that the sand should pass completely through a 25-mesh standard sieve, and not more than about 30 per cent of it should pass through a 50-mesh standard sieve. The well-known moulding sands are of this character, Boswell having found the percentages of such grains in the moulding sands given in Table XLII.

TABLE XLII.—MEDIUM SANDS (Boswell)

Locality.	Percentage of Grains between 0.01 and 0.02 in. diameter.
Bawtry	95
Belfast	55.5
Birmingham	67.1
Belgian yellow	64.9
Heck	77.0
Mansfield (open)	78.8
St. Erth	86.5
Worksop (pot)	76.2

The finer sands, which are largely used for facings, consist chiefly of grains between 0.004 and 0.01 in. diameter, which pass completely through a 50-mesh sieve, but are retained on a 125-mesh sieve, as shown by Table XLIII., compiled from data obtained by Boswell.

TABLE XLIII.—FINE SANDS (Boswell)

Locality.	Percentage of Grains between 0.004 and 0.01 in. diameter.
Durham	63.4
Erith (mild)	87.5
French red	62.7
Huttons Ambo	72
Leighton Buzzard	75.8
South Cave	90.2

Other much finer sands are available, the finest Worksop sand containing, according to Boswell, 62.5 per cent of grains less than 0.004 in. diameter.

Floor or backing sand does not come into contact with the metal, except in the roughest castings, and may therefore consist of coarse rounded grains, though an excessively coarse sand should be avoided.

Sands for *cores* should be between 50- and 75-mesh. Coarser sands should not be used, on account of their weakness. A sand

consisting of grains of 35-mesh when new may be as much as 40 per cent weaker than a 50-mesh sand. Excessively fine sand should not, however, be used, as its permeability is usually too low.

Facing sands must be sufficiently fine in texture to give smooth castings, and the finer the detail of the article to be made, the smaller must be the grains of sand. The finest "art castings" should be made with the finest-grained sands. For delicate bronze work, sand which passes through a 250-mesh sieve may be used. On the other hand, fine sands contain very small pores and so have less venting power; hence, the finest-grained sand consistent with the safe venting of the mould should be used, as such a sand will give the casting the smoothest surface possible under the circumstances.

Parting sands should be ground finely so as not to separate the parts of the mould too much. If too coarse a sand is used, some of the metal may run between the parts of the mould and necessitate an excessive amount of fettling or grinding of the castings. The grains in a parting sand should also be as uniform in size as possible (see p. 78).

The *effect of the size of grains on the metal* to be cast is often important. The case of aluminium has been mentioned on p. 106. Brass and bronze require finer sands than iron, on account of their "searching" or "penetrating" action on the mould (p. 83). For this reason it is also necessary to tamp brass moulds more tightly than those used for iron, etc., and thereby to produce a harder surface.

The *effect of the size of the grains on the refractoriness* of the sand should not be overlooked. As quartz has a very low heat-conductivity, large grains of sand are more resistant to high temperatures than small ones, because the heat does not penetrate so readily into the large grains.

The figures shown in Tables XLIV., XLV., and XLVI. show the sizes of grain in well-known moulding sands from different parts of the country.

TABLE XLIV.—SIZES OF GRAINS IN MOULDING SANDS (J. Shaw)

Sieve No. . . .	30	60	90	150	Less than 150
Erith (weak) . . .	0.40	0.86	0.56	67.88	30.46
" (medium) . . .	0.19	0.84	0.28	38.87	58.08
" (strong) . . .	1.32	4.55	1.22	14.08	76.02
Lancashire . . .	0.80	4.14	39.05	13.02	4.58
N. Midlands . . .	0.01	1.28	29.30	54.60	14.23
Worsop (fine) . . .	0.38	0.92	3.38	39.16	54.26
" (coarse) . . .	0.15	2.63	15.12	60.93	19.98
Stourbridge . . .	0.49	6.41	17.82	49.89	24.70
Wolverhampton . . .	0.54	1.32	13.50	47.69	35.94
Kidderminster . . .	0.08	1.60	16.99	55.84	20.84
Southampton . . .	0.20	1.40	14.80	69.20	13.32

TABLE XLV.—SIZES OF GRAINS IN MOULDING SANDS
(Sexton and Primrose)

	Clyde River.	Belfast Red.	German Yellow.
Through 100-mesh	4.3	81.0	78.0
" 80 "	2.1	2.6	3.0
" 60 "	8.4	4.0	6.5
" 40 "	29.0	3.5	5.0
" 20 "	40.5	6.5	4.0
Retained on 20-mesh	14.2	1.5	1.5
Average fineness	31.9	88.7	88.3
Loss	1.5	0.9	2.0

TABLE XLVI.—SIZES OF GRAINS IN MOULDING SANDS
(P. G. H. Boswell)

Material	Very coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Coarse silt	Fine silt	Clay	Total sand Grade.
Size of grains	in. Above 0.01	in. 0.02-0.04	in. 0.01-0.02	in. 0.001-0.01	in. 0.002-0.01	in. 0.0001-0.002	in. Less than 0.0001	in. Over 0.04
Sieve No. . . .	12.5	25	50	125	250	*	*	..
<i>British</i> —								
Anchenheath rock	25.7	1.8	41.1	26.2	0.2	1.0	4.0	94.8
Cornish red . . . .	..	0.6	37.3	42.7	5.7		13.7	80.6
Dorham . . . .	..	Trace	3.7	63.1	8.2	15.6	9.1	67.1
Huttons Aulmo . . . .	..	0.1	18.1	72.0	0.2	0.3	11.0	88.5
Leighton Buzzard . . . .	..	..	6.7	75.8	3.3		12.7	81.0
South Cave . . . .	..	..	8.3	90.2	0.7		0.8	98.5
<i>Foreign</i> —								
Belgian red . . . .	..	2.9	36.5	11.2	6.6	22.2	20.6	50.6
Belgian yellow . . . .	..	7.5	64.9	12.0	3.3		12.3	84.1
French red . . . .	..	0.6	18.0	62.7	3.1		15.6	81.3
French yellow . . . .	..	..	3.5	60.6	9.0	10.0	16.9	64.1

* No sieves exist which correspond to fine silt and clay.

Other mechanical analyses of moulding sands will be found in Boswell's *Memoir on British Resources of Refractory Sands for Furnace and Foundry Purposes*.¹

Specifications for Moulding Sands.—There is no "ideal moulding sand," nor is a sand which is completely satisfactory for one kind of casting equally suitable for another. Moreover, a sand may

¹ See footnote, p. 89.

be used for facings in one kind of foundry and as a backing sand in another.

For this reason it is impossible to issue any "standard" specification which is equally suitable to all foundries. Considerations of cost compel foundrymen to use local sands as far as possible and to make good their defects by various means. (See *Preparation*, p. 113.) Any special work may necessitate the purchase of sands particularly suitable for it.

The following notes indicate broadly the properties required to be possessed by the various sands named :

Sands for general foundry use should consist chiefly of silica, the grains of which should be as uniform in size as possible, each particle being covered with a thin film of clay, limonite, or other bond (p. 115). The sand should have a refractoriness or heat-resistance greater than is required in the particular work for which it is employed, so as to reduce "burning on" as much as possible ; at the same time other properties should not be unduly sacrificed to securing a high degree of refractoriness. The permeability (p. 82) should be high so as to permit the ready escape of the gases, this being more readily obtained with a sand composed of rounded grains of uniform size than with a sharp sand composed of mixed grains (p. 105). The plasticity and cohesion of the sand (p. 93) should be high in order that the moulds may be of ample strength, but this must not be obtained at too great a sacrifice of permeability.

So far as chemical analysis is concerned, a very high proportion of silica is always an advantage. Iron oxide should usually be high, except possibly for sand used for some of the most difficult steels ; alumina in the form of clay may be moderately high, but there should not be sufficient clay to reduce unduly the permeability. The percentage of lime, magnesia, potash, soda, and all other impurities should be as low as possible, though in sands used for casting brass and other alloys melting at a relatively low temperature the presence of lime is not usually harmful.

Moulding loams in which no patterns are used must be more plastic than ordinary sand. The following properties are desirable : (1) plasticity ; (2) small shrinkage ; (3) sufficient refractoriness ; (4) cheapness.

Loams should conform to the requirements mentioned above, and should contain sufficient clay to bind the particles of sand into a strong enough mass, but there should not be sufficient to cause cracking or excessive shrinkage. The sand should be sufficiently refractory to avoid "burning on," and its texture should be sufficiently fine for the castings to have a good surface.

Facing sands should conform to the general requirements given above, but should also be sufficiently fine for the particular castings to be made. They should impart a smooth, fine surface to the metal with which they come in contact, and should allow the castings to leave the mould cleanly after cooling, without being covered with adherent sand.

Core sands should conform to the general requirements mentioned above, except that some other binder should be substituted for the clay. The mixture should have the greatest possible strength and, at the same time, sufficient venting power, yet when the casting is finished the cores should readily be broken up and removed; this cannot occur if much clay is present, as the clay is "baked" and hardened by heat.

Parting sands should consist of fine, uniformly rounded grains, free from clay or other binding material and also from fluxes, especially soluble salts and lime compounds.

For *casting steel* and other high-temperature alloys, the moulding sand must be highly refractory, but for reasons of economy two sands are sometimes used: (a) a highly refractory facing sand composed of very pure sand and fireclay or a natural sand equivalent thereto, and (b) a backing sand of a less refractory nature whose chief characteristic is its permeability.

For *casting brass and other non-ferrous alloys* a less refractory sand will suffice, provided its heat resistance is sufficient for the particular metals to be cast.

Sources of Moulding Sands.—The supplies of the best natural moulding sands are very limited, and are practically confined to St. Erth, Cornwall, Huttons Ambo, South Cave, and Barrow-in-Furness, and to certain French, Dutch, and Belgian sands. Sands of inferior refractoriness, but quite suitable for some iron castings and for many non-ferrous ones, are more widely distributed, and occur chiefly in the Trias, Greensand, and Eocene formations, as well as in the older Carboniferous and other rocks which supply sharp rock sand. In general, sands which are freshly dug are preferred to those which have been exposed to the weather for a long period of time.

As far as possible, foundrymen use local sands for general work and supplement these by specially purchased facing sands, but very often the whole of the sand used is brought considerable distances, when an equally suitable sand might be obtained much nearer the works. Sands such as those of Erith, Mansfield, etc., have been carried to Africa, India, Australia, America, when perfectly satisfactory sands could readily be obtained much nearer. For reasons previously stated, it is impracticable to give in detail each source of sand and the particular castings for which it is most suitable; and to arrange the sands in groups according to the purposes for which they are used would involve much needless repetition, which is avoided by mentioning them in the order of their geological occurrence.

Glacial sands are worked for moulding sands at Oldham and in various other parts of Lancashire, where they are used for general casting; at Bawtry (South Yorkshire), where they are employed to some extent for non-ferrous work; at Ipswich for steel casting; and in Durham for general purposes.

Pliocene sands include the famous Cornish red and yellow sands

of St. Erth, which are used for general casting and to some extent for steel.

The *Bagshot beds* of Southampton are used to a small extent for general work.

The *Thanet sands* obtained at Erith, Charlton, Woolwich, and Rochester, both from pits and by dredging, are largely used for all kinds of moulding work, and are so highly valued that they are transported as far as Edinburgh, Northumberland, and Durham for non-ferrous work. These sands, when mixed with an opener and sufficient clay, make an excellent loam for general iron castings and for dry facings. The Thanet sands are superior to the Bunter sands for moulding purposes, as the latter may contain up to 15 per cent of felspar, and so are less refractory.

The *Greensands* of Leighton Buzzard are used for casting steel, whilst those of Devizes and Seend are used in the west of England for general and heavy work, but are too coarse for fine work.

The *Kellaways sands* of South Cave in Yorkshire are used for casting steel and for general moulding.

The *Upper Estuarine sands* of Huttons Ambo, Yorkshire, are used for casting steel.

The *Bunter sands* are amongst the most valuable moulding sands in the country for iron and most metals other than steel. Their value is partly due to the iron oxide bond which they contain. Useful moulding sands in this series are obtained near Birmingham, Stourbridge, Wolverhampton, Compton, Wombourne, Kidderminster, and Stourport. They are similar to the Lancashire sands, and are largely used locally for non-ferrous and other work. When mixed with manure, they make good dry facings for iron.

In Birmingham they are used for casting gold, silver, nickel, copper, brass, phosphor-bronze, white alloys, aluminium, etc.

The sands around Wolverhampton and Stourport are specially fine, and are suitable for facing sands, whilst the Wombourne sands are particularly suitable for casting brass.

The Bunter sands of Mansfield, Nottingham, Worksop, Sutton Junction, Hemphill, and Lenton, in Nottinghamshire, Doncaster, Armthorpe, Bawtry, Heck, Hensall, and Whiteley Bridge in Yorkshire, are very well known, and are widely used both for ferrous and non-ferrous foundry work. The finest Mansfield sands are excellent as either dry or green sand facings for brass work. Some Mansfield sand is used in Edinburgh, Northumberland, and Durham for non-ferrous work. Milled with horse-dung, it makes a good dry facing for iron castings. The upper beds at Mansfield are also used as pig-bed sand.

The Worksop red sand is very good for floors. The Doncaster sand is suitable for general jobbing work, but if carefully screened could be used for better work. It is largely used for casting iron and for small cores, but it is not usually strong enough for loam moulding.

At Bawtry the Bunter sand is worked for pig-beds and for rough general work.

The Bunter sands of Durham and Cumberland are used for general work and also for non-ferrous moulding.

At Runcorn in Cheshire the sands are fine and of a deep red colour, and are chiefly used as pig-bed sands. Bunter sands are also worked at Ormskirk in Lancashire, providing an open and a close moulding sand.

The Belfast sand is a fine-grained reddish material much used for light ornamental work and for hollow ware; it is regarded as one of the best sands for casting brass and cores, and is extensively used as facing sand, especially for brass and non-ferrous metals, sometimes with an admixture of rock sand. For non-ferrous work the sand is used repeatedly, new sand being added as required. It becomes finer in use and, therefore, more suitable for certain work.

The *Permian sand* of Pontefract and Castleford is similar to the Doncaster Bunter sand, and is used, to some extent, for general work as well as for non-ferrous work in South Yorkshire, particularly in the Sheffield, Hull, and Leeds areas. The Permian sand of Lancashire is used for general iron casting, and is mixed with floor sand and coal-dust facings. It is very useful for dry sand moulding. Whilst usually uniform, it requires watching, as it sometimes contains lumps of clayey material.

Carboniferous sandstones are, to some extent, crushed for moulding sands.

The *Clyde "Rotten Rock,"* which is worked at Auchenhearth, Drumevil, Garngad, Garukirk, Glenboig, and Drumbathie in Lanarkshire, is used as a facing sand, and gives very smooth castings. It is also employed for non-ferrous work round Glasgow in conjunction with sand from Carlisle and Belfast.

Falkirk sand is used for casting hollow ware in the Glasgow district. It gives a very smooth finish, which is well known in the production of Scotch irons from the Glasgow district. At Haydon Bridge, Northumberland, a sandstone or bastard ganister is used for casting steel.

Preparation of Moulding Sands.—When a wholly suitable natural sand is available the only preparation it usually requires is *screening* to remove the excessively coarse particles (l. 441), and *drying* to remove any excess of moisture (l. 401) which may be present.

Drying.—When a natural sand is to be mixed with other materials it is almost impossible to obtain a uniform product unless the ingredients are first dried, and apart from this it is important that any sand used for moulding should not contain more than 4.5 per cent moisture (see p. 100). If it contains more moisture it should be dried as described in Vol. I. p. 401, care being taken, if the sand contains clay, that no part of it is heated to a temperature above 110° C., otherwise some of the clay will be decomposed and spoiled. This preliminary drying is often neglected, although it is most important. It is not sufficient to leave the sand out in the sun or in a current of cold air.

The moulds, unless used for green^c moulding (p. 76), must be dried prior to use. This drying is sometimes effected by directing the flame of a lamp on to the interior face of the mould, but smaller moulds, especially those in which oil or other organic matter is used as a bond, are usually baked in an oven at a temperature of about 300°-450° C. This greatly increases the strength of the mould, but it does so by decomposing the bond, and thus makes it difficult, or even impossible, to use the material for making fresh moulds.

As completely suitable natural sands are rare, it is usually necessary to treat the most readily available sands so as to render them more suitable. The methods adopted for this purpose are : (a) screening to remove the particles of unsuitable sizes, (b) adding sand from another source or some other material to make up for the deficiencies in the sand chiefly used, (c) adding water to increase the plasticity of the sand or mixture, and (d) milling or mixing the various sands and other materials.

Screening is important as a means of removing any lumps, of breaking up any clots, and to secure a uniform product. One of the following sieves should be used for these purposes :

Floor sand	$\frac{1}{2}$ -in. mesh.
Facing sand (coarse)	$\frac{1}{4}$ -in. mesh.
Facing sand (fine)	$\frac{1}{8}$ -in. mesh.
Parting sand	$\frac{1}{16}$ -in. mesh.

The material should be passed repeatedly through these sieves until a uniform material is obtained, as very thorough screening is desirable for the production of good work. Plain screens inclined at a suitable angle are generally used (I. 442). A suspended, reciprocating, flat sieve is also very satisfactory. Rotary sand sifters (I. 456) are also largely employed, the polygonal shape being preferable.

Very small particles, if in excess, must usually be removed by washing (I. 384), the bond thus separated being replaced by material from another source.

Artificial Mixtures.—The mixing of several sands, or of one or more sands with clay or some other binding agent, in order to produce a mixture having all the desired properties, has long been part of the work of many foundry managers. Thus, it is customary to mix a strong sand with one rich in silica : by this means the desirable properties of the first sand are retained, but the coarser mild sand increases the proportion of voids and enables the vapours and gases produced during the process of casting to escape more readily. A sand may not have the texture required for a particular purpose, but this can be obtained by mixing two or three sands together. A coarse sand may be added to another sand or to a mixture to “open” it, whilst a high silica sand might be added to give refractoriness. Sometimes a sand may be added to another to reduce the proportion of clay present in the former, whilst if the sand which forms the basis of the mixture does not contain a sufficient proportion of

bond, a highly ferruginous sand, a sand rich in clay, or even a fine clay or kaolin, may be added.

Some firms use an unnecessarily large number of sands in their mixtures. Two sands, if skilfully selected, are usually sufficient, and only in rare cases is a third required. The complex mixtures in which five or six sands, as well as one or more bonds, are used, are the result of a method of trial and error which may give good results, but is unnecessarily costly. In most cases a much simpler mixture would be equally satisfactory.

In all artificial mixtures used for moulding sands there are only three essential ingredients, viz. the quartz grains, which constitute about nine-tenths of the whole material, the bond, and, in the case of sands which require to be very porous or to produce a fine surface on the casting, a carbonaceous material which burns away when the metal has entered the mould.

The *sand* which is the source of the quartz grains should conform as nearly as possible to the requirements mentioned on p. 79. It should be sufficiently pure not to fuse or sinter when in use, and the grains should be of such a shape (p. 104) and size (p. 105) as to meet the particular requirements of the moulder. As far as possible the grains should all be the same size, so as to secure the requisite permeability. Very fine sand and silt should be absent, or at least there should be as small a percentage as possible of these materials (p. 106).

Facing sands are usually composed of much smaller particles than other sands, so as to impart a smooth surface to the casting. Where very small grains are required the sand is usually ground in a ball mill to the desired fineness. In order to prevent any coarse material being used as a facing, the sand is applied to the mould by means of a dust bag, which retains the coarse particles and permits only the fine grains to pass on to the surface of the mould.

Sands which contain an excessive amount of clay may be improved by grinding them with a suitable proportion of sharp sand. In some cases, where a large proportion of lean clay is present, it may be desirable to add a sharp clean sand and then add enough plastic clay to secure the necessary binding power.

The *bond* may be of clay, ferric hydroxide, or of some organic substance. In natural moulding sands the bond is usually either clay or limonite (ferric hydroxide) or a mixture of these substances. Sometimes a little organic matter is present, but organic bonds are chiefly found in artificially prepared sands.

The purpose of the bond is to form a plastic and coherent mass which can be made into moulds of the desired shape and with sufficient strength to resist the stresses to which they are subjected when in use.

The advantages of clay as a bond are its great plasticity and binding power and its cheapness. Its chief disadvantage is that when heated it forms a hard, strong mass which is useless for

making other moulds, though used sand containing clay as a bond can, to some extent, be "restored," as described on p. 126.

Considerable care and skill are required to obtain a suitable clay. Fireclays are largely used on account of their refractoriness and binding power, but they are difficult to distribute uniformly through the sand, and generally impart an undesirable "stickiness." An excess of clay should always be avoided, 3 per cent being usually sufficient, as it reduces permeability and wastes too much sand by forming a "burnt" stony material. If a sufficiently plastic clay of high refractoriness, other than fireclay, is available it should be tried, as fireclays are by no means pure and contain too much fine sand and silt to be really satisfactory. The objection to the highly plastic ball clays is that they sinter at too low a temperature; otherwise they would be superior to fireclay, being much richer in true clay.

Damp clay cannot be thoroughly mixed with sand, so that where possible it is better to introduce the clay in the form of *clay-flour*, which is produced by grinding to powder pieces of clay which have been partially dried in a stove, great care being taken not to allow the temperature of the clay to exceed 110° C. during the drying or it will be partially decomposed and its binding power will be reduced. A further advantage of clay-flour is that an exact amount can be introduced into each mixture, whereas with a damp clay much less accuracy is attained.

Limonite, or other forms of ferric hydroxide, are excellent as a natural bond, but very difficult to prepare in a form suitable for making an artificial bond. They should be present in the sand or mixture as a colloidal gel, and not merely as a precipitate, and the difficulty of preparing a suitable gel equally distributed over the surface of the grains of sand is very great. At present, the best method of introducing iron compounds is to use some form of ochre (which is a natural mixture of colloidal iron hydroxide and clay) as recommended by Kampmann in 1845, but this is by no means wholly satisfactory. Haematite ore has been used, but this is not sufficiently colloidal. As a general rule, sands for iron casting should not contain more than 5.5 per cent of iron, and for brass casting not more than 7 per cent.

Colloidal silica has been used to a small extent as a bond, but the difficulties connected with its preparation and use are as great as those with colloidal iron compounds.

Many organic substances are available as binders, and are particularly useful where it is undesirable that the sand should be made permanently hard, as is the case when a sand containing much clay is heated to a high temperature. Sands containing carbonaceous materials do not form a hard stony mass, but are readily broken up even after prolonged heating; they are, therefore, very useful in core sands, where they are largely used in place of clay as a binder.

The organic binders most generally used are flour, gluten,

core-gum, or other forms of starch, glue, glucose, treacle, molasses, sugar, or viscous material obtained by evaporating the sulphite liquor resultant from converting wood into paper, oil (especially linseed oil), resin, and sour beer. Some of the above bonds are also sold under fancy names. These bonds all burn away as soon as they are heated by the molten metal, and so produce a porous mould, from which vapours and gases can readily escape.

Flour provides a glutinous substance which is a fairly efficient binder, but to get the best results the flour should be rubbed with water, the starch grains allowed to swell by remaining all night in contact with the water, and the mixture should afterwards be boiled, so as to produce a starch paste, before it is mixed with the sand.

Gluten and *core gum* are similar binders, the latter being prepared from starchy materials such as potatoes; about 5-10 per cent of gluten is required. In France a preparation consisting essentially of gluten or gliadine, termed *agglutinol*, is sometimes used for casting bronze. *Glucose* has been used to the extent of 2.5 per cent for malleable steel casting. All these materials are useful as binders; the chief objection to them is that they readily absorb moisture, and so tend to cause dewing on the surface of the moulds and cores; if the metal is poured into the "bedewed" moulds, blowing is almost certain to occur. Where the moulds and cores are used quickly there is no objection to the use of a glutinous or starchy binder, but they should not be kept in the wet state in stock a long time. The decomposition of the starchy and glutinous materials is another undesirable feature. Such mixtures should not be used when casting aluminium.

Treacle, molasses, sugar, and old beer are also useful binders. One part of treacle to 25-30 parts of water is commonly used; too "thick" a liquor does not distribute itself properly among the grains of sand.

Oils of various kinds are used as binders, *linseed oil* being particularly popular for moulds for various metals, including bronze. For iron, mixtures of linseed oil and dextrin, or linseed oil and molasses, have been used, 2.5 per cent being required. For very complicated cores, 2-6 lb. of whale oil to each 200 lb. of sand has been used. Two parts of whale oil and one part of boiled linseed oil is also very satisfactory. Fish oils are undesirable on account of their odour. Cores made with sand with about 3 per cent of oil are very useful in casting the combustion chambers of gas and oil engines and the parts of cylinders where the core is entirely surrounded by metal.

The amount of oil required varies with the size of the particles of sand and the proportion of clay present. As clay absorbs oil, a larger quantity will be required than when a clay-free sand is employed. It is a mistake to use damp sand or to add water when using oil as a bond, as water acts as a repellent to oil and prevents the grains of sand from being uniformly coated with oil.

Moulds, and particularly cores, made of sand bonded with oil are cheap; when properly dried they are hard, and will maintain their proper form and firmness with a minimum of support from core rods and irons; they are also very permeable; an excess of oil, however, must be avoided. The drying or baking of oil-bonded moulds and cores needs care, as they crumble away if overheated, whilst if "dried" at too low a temperature, or for too short a time, a large amount of gas is produced when the mould is being poured. When properly dried or baked, water should be absent, and there should be just sufficient oil left in the sand to keep the core firm and hard. The proper drying of oil-bonded moulds and cores can only be learned by experience.

Resin is used as a binder, especially in small cores of complicated shape, for which it is very suitable, 1-3 per cent being usually employed.

Any solid organic binder must, of course, be finely ground so as to be evenly distributed through the sand.

The amount of organic binding material used should be as small as possible, on account of the amount of gas evolved, and also because an excess of bond does not carbonise properly, and so produces a weak mass unless an excessive amount of heat is applied in drying or baking; in the latter case the carbonaceous matter is partly volatilised and partly converted into useless carbon or "char," so that its binding power is lost.

All artificial bonds, other than clay, are weak, though some, such as oil, produce strong moulds and cores after the latter have been baked or dried. There is ample scope for the invention of new bonds which will give the moulds the same strength as the clay in natural moulding sands without the "burning" which necessarily occurs when clay is heated. The chief advantage of organic binders over clay is that sands containing the latter "go dead" when used, because the heat from the molten metal bakes the clay and the sand in immediate contact with it, producing a stony or brick-like material which cannot easily be separated and which cannot be reconverted into clay. The organic bonds are destroyed, but they do not damage the sand to the same extent as clay.

Openers are materials added to a moulding sand to increase its permeability. They usually consist of organic substances such as sawdust, coke- or coal-dust, or various waste products, such as horse-dung or manure, cowhair, and pease-meal. Cinders from blast furnaces are also sometimes used. *Ground silica rock*, or preferably *ganister*, which contains about 5 per cent of clay, is largely used to open up fine sands and composites (p. 79). Oil, treacle, and other organic binders (p. 117) also act as openers.

Any material, to be suitable for "opening" or increasing permeability, may be in the form of a liquid, such as treacle, etc. (p. 117), or of a solid. If the latter, it must be sufficiently finely ground to avoid the formation of unduly large pores.

The proportion of opener to be added depends so much on the nature of the castings to be made and on that of the sand used that no definite figures can be given as of general application. Too little opener will obviously fail to allow the gases to escape properly; too much will be wasteful of a material which is more costly than the sand, and a very large excess may so weaken the sand that it cannot be used satisfactorily. As the sand is used over and over again the proportion of opener present tends to increase, so that a used sand does not require so much opener as a new sand. Whatever opener is used, it should be free from a high percentage of ash or it will reduce the heat-resistance of the sand.

Facing sands are frequently opened with organic matter, which not only permits the gases to escape, but, being of a neutral character, facilitates removal of the metal by assisting in preventing the adherence of the sand; it also aids in producing a smooth surface on the casting. When the molten metal comes in contact with the opener (*e.g.* coal-dust), there is an instantaneous generation of gas which forms a layer just for an instant before passing through the mould and persists sufficiently long to cause the metal to glide over without affecting the mould; again, with another opener, such as oil, the heat of the molten metal may cause the sublimation of hydrocarbons from the rich gases, which persist sufficiently long to have the same effect and are afterwards absorbed into the metal or burnt away. Both actions may take place in the same mould, and it is claimed that a film of graphite, if ground very finely, will burn and produce gas in a similar manner. The action of coal-dust may readily be demonstrated by making two green sand moulds, the facing of one containing coal-dust and the other being used without it. The castings produced in the mould without coal-dust will be of a dirty white or grey colour, on account of their being covered with a skin of partly fused silicates derived from the oxides in the sand. Such skins are often removed only with great difficulty from the castings. When coal-dust or equivalent material is used, however, a clean casting is produced. The use of coal-dust in this way is not always desirable, as it may have the same effect as working cold-short metal. This is, according to Sharp, especially noticeable at the teeth of small spur wheels, which should not be cast in facing sands containing coal-dust. An excess of coal-dust is undesirable for preparing castings which are to be annealed, as too much carbonaceous matter forms a skin of magnetic iron oxide on the castings and prevents their proper annealing. This precaution is specially important if the articles are afterwards to be tinned.

The presence of coal-dust in brass-casting sands is also harmful, as it tends to cause pitting and irregular vein-marks on the finished article. The addition of pease-meal (p. 118) is more satisfactory for the purpose.

Where coal-dust can be used satisfactorily, it is generally added

in the form of a finely-ground, rich gas-coal or sea-coal, such as that mined in South Wales. The coal should contain at least 35 per cent of volatile matter and less than 10 per cent of ash. An excessive proportion of ash will cause the castings to have a whitish-grey appearance and a rough surface.

The size of the particles of coal-dust varies according to the nature of the castings to be made; for very light castings an exceedingly finely-ground dust is desirable, whilst a slightly coarser yet still fine "grist" should be used for heavier work. The medium and coarse grades of coal-dust will be required for the larger classes of castings, in which it is necessary for the generated gases to be carried away quickly. When coal-dust of too coarse a grade is used, small "pits" are left on the face of the casting.

The proportion of coal-dust or other opener depends on the nature of the castings, but is usually between 5 and 15 per cent of the weight of the sand. The heavier they are, the greater must be the proportion of opener in the sand, but too much must be avoided, as it will give the castings a "veined" appearance. For motor cylinders and similar light castings, 1 part of coal-dust to 10 parts of sand is usually satisfactory, whilst for heavy work 1 part of coal to 7 parts of sand is better. McWilliam and Longmuir recommend 1 part of coal-dust to 8 or 9 parts of sand for castings exceeding 3 in. in thickness, whilst Sharp suggests the following composition for a good facing material:

Black floor sand	.	.	.	10 parts.
New river sand	.	.	.	5 "
Coal-dust	.	.	.	1 part.

For high-temperature work the more modern practice is to discard the use of an opener in the facing sand and to use sand only, the finished surface of the mould being coated with a "blackening" composed of graphite, coke, or charcoal (p. 78). Such coatings have the same effect as the presence of carbonaceous matter in the sand itself, but with the advantage that they do not contaminate the sand. In the older practice the coal was mixed with the facing sand, and when a layer of facing sand about 1 in. thick was used only a small proportion of the coal in that layer was gasified, so that if the facing sand was used over and over again or mixed with the floor or backing sand the latter would gradually become too lean to be used, on account of the increasingly large proportion of coal-dust. The more modern method of using a plain sand and a coating of blackening simplifies the moulding, as only one sand heap is used: since the latter is far less liable to be contaminated with carbon, both labour and money are saved.

The mixtures given in Tables XLVII., XLVIII., XLIX., L. are typical of the moulding sands artificially prepared and used in various parts of the country.

COMPOSITION OF MOULDING SANDS

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TABLE XLVII.—FACING SANDS FOR CASTING IRON

	Parts by Volume.				
	A.*	B.*	C.*	D.†	E.†
New sand	20	20	40	5	3
Black sand	30	..	20	10	3
Coal-dust	5	..	9-10	1	..
Road sand . . . . .	..	20	20	..	..
Red sand . . . . .	..	..	..	..	2
Manure . . . . .	..	2-4	..	..	..

* Sexton and Priorose, *Principles of Iron Founding*.
† J. Sharp, *Modern Foundry Practice*.

TABLE XLVIII. LOAMS

	Parts by Volume.					
	A.*	B.*	C.*	D.*	E.†	F.†
Black sand . . . . .	..	..	..	..	82	..
Sharp sand	75	85	68	81	..	59
Rock sand	12½	15	19	..	..	23
Clay . . . . .	..	..	..	9	18	18
Manure	12½	..	13	..	..	..
Sawdust . . . . .	..	..	..	10	..	..

* Buchanan, *The Moulder's Dictionary*.
† J. Sharp, *Modern Foundry Practice*.

A is for cast iron, B and E are heavy loams for large work, C is a lighter loam for medium-sized work. All three should be milled with clay water. D and F are facing loams.

TABLE XLIX. CORE MIXTURES

	Fine.	Medium.	Heavy.
New sand	71	44	39
Road sand . . . . .	..	44	11
Floor sand	24	12	39
Manure	5	..	11

The ammonium chloride in C (Table L.) sublimes when heated, thus giving a clean face to the casting. Mixture G requires to be mixed with dextrin solution, as it has no intrinsic binding power.

Floor sands should consist of an open sand of moderate cohesion, such as red Worksop or yellow Erith sands. As they are used repeatedly they gradually become contaminated* with burned clay, carbonaceous matter, etc., and should therefore be sifted occasionally,

TABLE 1.—COMPOS FOR CASTING STEEL

	For Castings up to 2 in. thick.			For Castings over 2 in. thick.			
	Parts by Volume.			Parts by Volume.			
	A.*	B.*	C.*	D.*	E.*	F.†	G.†
Old facing sand . .	53	60	69	5	..	..	..
Old crucibles . .	13	..	..	50	..	..	..
Fire-bricks . .	13	..	..	25	..	16	..
White clay . .	14	5	..	15	20	16	..
Fireclay . .	..	..	9	..	..	..	..
Coke-dust . .	7	..	..	5	..	..	..
White silica sand . .	..	25	17	..	80	..	50
Graphite . .	..	10	..	..	..	68	50
Ammonium chloride . .	..	..	5	..	..	..	..

* Buchanan, *The Moulder's Dictionary*.

† Beckmann.

as otherwise they become lean and useless. (See also *Restoration*, p. 126.)

Milling.—The term "milling" is applied in foundries to two entirely distinct processes, namely (a) the crushing or grinding of pieces of material which are too large to be of use and, therefore, require to be reduced to much smaller-sized pieces, such as sand, and (b) milling proper, which consists in mixing the various materials together so as to form a perfectly uniform product.

The *crushing* of materials used in moulding sands is usually done by the firms who supply them, but used sand, broken crucibles, etc., may require to be crushed in the foundry. For this purpose, a high-speed disintegrator (I. 352) is usually the most convenient and satisfactory machine: a popular one consists of three concentric cages, one stationary and the other two revolving at about 1000 revs. per min.; this mill requires about 3-4 h.p., and will treat 2 tons of sand per hour. Some of the other disintegrators described in Vol. I, pp. 352-356 are quite satisfactory.

Whilst a disintegrator is best for general work, a ball mill (I. 365) must usually be employed when a very fine powder is required. Centrifugal mills of the Griffin type (I. 371) have also been used satisfactorily.

The crushed material should be screened (I. 441), no unduly large pieces being present.

The proportioning of the various materials which enter into the composition of a prepared moulding sand is sometimes effected by weighing and sometimes by measuring them. Weighing is much more accurate, and should be adopted wherever possible. When it is not desired that the workmen shall know what proportions are employed, specially made weights are sometimes used. These have the additional advantage of making mistakes more difficult, as only one weight is used at a time.

Adding Water.—There is considerable difference of opinion as to when water should be added to the sand or sand mixture. If the materials are prepared dry and water is required to render the mixture plastic, it should usually be added in the mixing or milling stage, but some foundrymen prefer to add the water to the milled sand and then lay the latter aside for some time to allow the water to become uniformly distributed. Uniformity of distribution of the moisture is so essential that no pains should be spared to secure it. If, for any reason, it is thought best to add the water after, instead of just prior to, the milling, a period of storage is essential, after which the sand should be passed repeatedly through a $\frac{1}{4}$ -mesh sieve until it is reasonably certain that the moisture is uniformly distributed. Sand which has been milled and become too dry may be sprinkled with water, allowed to stand overnight, and then screened repeatedly. It is most important not to add too much water, and only in exceptional circumstances should the milled sand contain more than 6 per cent of water.

The *milling proper* or *mixing* of the materials in the desired proportions is a very important process, and it is necessary that it should be properly done, as otherwise a large percentage of waste castings will be produced. Moulding sands which have not been sufficiently milled are irregular in composition and unreliable in use; over-milled sand, especially in medium and heavy work, spoils the surface of the metal on account of its being so impervious to gases.

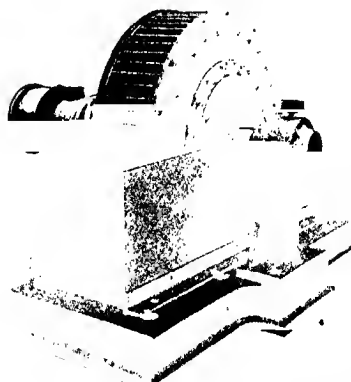
Before the introduction of machine milling, moulding sands were mixed by hands and feet, the material being alternately trodden and scraped down with a round stick. The kneading produced by this treatment mixed the sand very thoroughly and secured the uniform distribution of the moisture through the mass. The process, however, took from 1-3 hours, and was tedious, slow, and expensive, though very effective. Another method of mixing by hand consists in stirring the materials several times and passing the rough mixture through a sieve, the stirring and sieving being continued until each particle of sand is covered with a film of binder. At the present time, mixing is done almost entirely by machinery, but sand for heavy castings should not usually be milled, as this treatment reduces the porosity and permeability. Hand mixing is best for such sands, unless they are artificially prepared from sand and clay or some other binder, when milling may be necessary to ensure the pasting of the grains with bond.

Mixtures of oil and sand also should not usually be treated in an edge-runner mill, as the grinding takes the edges off the sand particles where a sharp sand is used, and forms too much dust. If great care is taken, they may be milled satisfactorily, otherwise they should be rubbed by hand or mixed in a paddle-mill.

The purpose of the milling proper is to mix the sand and other

materials together so as to produce a completely uniform mixture of the desired consistency. It is not intended that the sand or rock should be ground during the mixing; on the contrary, all grinding action should be minimised as far as possible.

It is sometimes convenient to effect a preliminary mixing, say of sand and coal, by passing the materials which have been roughly mixed by hand through a disintegrator, but the objection to such treatment is that, in the subsequent sifting, materials are removed, which alters the proportions of these in the powder. If a machine of suitable design is used, excessive grinding may be avoided and a thorough mixing effected. A typical sand-mixer of the Carr type is shown in Fig. 5.



G. E. V. Hall, Sheffield.

FIG. 5.—Sand-mixer.

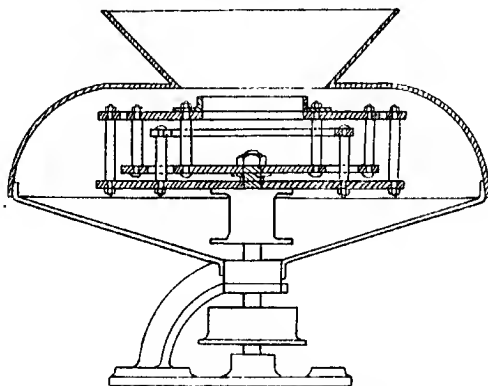
It is often convenient to use a horizontal mixer in preference to a vertical one. In Hall's mixer (Fig. 6), four cages are mounted in pairs so as to revolve in opposite directions, the outermost and third cages being driven by a pulley loosely mounted on the shaft and the alternate cages being attached to the shaft and driven by a second pulley. The sand is thrown into the hopper and, after being mixed, falls in a heap on the floor around the machine. The use of roller bearings in this machine is an important feature.

It is very difficult to secure a sufficiently uniform product with a pug-mill or other appliance consisting of an outer casing with an inner revolving shaft carrying blades or knives, as the sand is not required to be in a sufficiently soft paste. A centrifugal sand-mixer made by Sellers consists of a shallow chamber in which a number of stirrers rotate, thus churning up the mass. This machine ensures very thorough mixing without altering the shape or size of the grains.

Much better results are obtained by a process of mulling, in which the materials are rubbed together on a plate by means of a muller, or, if this is too slow an appliance, by means of heavy rollers revolving on a flat pan and known as "edge-runner mills" or "pan mills." These machines effect a thorough kneading and mixing of the damp sand, and, when properly designed for the purpose, are superior to any other mixer for moulding sands, on account of the extent to which they coat the grains of sand with bond.

Edge-runner mills are used for milling moulding sands more than any other type of mixer. They are usually 3-6 ft. diameter, with a solid bottom or pan, runner, or rolls from 1 ft. 6 in.—3 ft. 6 in. diameter and 6-18 in. wide, and weigh 3-30 cwt., the most convenient being about 3 ft. diameter, 15 in. wide, and weighing about 12 cwt. They should not be too large or heavy, or they will crush the materials instead of mixing them.

The rolls may be plain, grooved, or fluted. The author has obtained the most effective mixings by means of an edge-runner mill with a revolving pan and three scrapers to ensure the material being turned over repeatedly and kept as long as possible beneath the runners. Some materials require a longer time for mulling



C. E. V. Hall, Sheffield.

FIG. 6.—Sand-mixer.

than others, but 20 mins. is an average period. As explained on p. 123, over-milling should be avoided.

Undue grinding may be prevented by keeping the runners slightly above the pan (a very small fraction of an inch is sufficient) and by driving the pan instead of the runners; the latter revolve as the result of the friction between them and the sand in the pan.

The material to be milled should contain just enough water to give it the required consistency when the milling is completed. It should not be wet enough to form a paste; on the contrary, the drier the sand, provided it has sufficient plasticity, the better.

Aerating Sands.—In order that sands which have once been used may be rendered permeable to gases, they are passed through a disintegrator (p. 124), which reduces any lumps or conglomerated masses to a loose powder. The process is known as aerating, though actually it is a simple crushing process.

Sifting is desirable after the sand mixture has been mulled,

as edge-runner mills tend to compress the material into cakes, which may cause "scabs" on the metal.

Maturing the Sand.—Most moulding sands are improved by storage in a cool and dry place for some hours, and still more so, if they can be kept without becoming too dry, for a fortnight, though a short storage of a few hours (say overnight) is better than none. This storage permits the water or other fluid present to distribute itself uniformly through the mass.

Reclamation of Old Sand.—Much valuable sand is thrown away as waste which might be reclaimed by suitable treatment. This is particularly the case with old facing sands and also with floor sands. Thus, the sand containing an excess of charred binder is often thrown away, but it has been found by W. F. Prince that by grinding it with a sharp rock sand much of this carbon film may be removed and the sand may then be supplied with a fresh organic bond and used as new sand.

Sand which has been used "goes dead" or is "burnt" chiefly because the binding agent in it has been destroyed by the heat from the molten metal or in the process of "baking" the moulds. The change is due entirely to the decomposition of the bond; in the case of a clay bond, the clay is converted from a plastic material composed of a large number of minute grains, each easily separated in water, to a hard, stony mass, which is devoid of plasticity and can only be reduced to powder by intensive grinding. Even then its plasticity cannot be restored by any artificial means; the clay is useless, and, what is worse, the sand particles which have been united with the burned clay are equally useless, as they cannot be separated from it.

Only that portion of the sand which has been heated sufficiently to decompose the clay is "dead" or "burnt"; the remainder is as good as though it had not been used. The difficulty is to separate the burnt sand from the unaltered material, and no wholly satisfactory method has been found. Some of the principal methods used are described later. With an iron bond (p. 99) a similar decomposition occurs, but the restoration of the iron compound is much more easily effected, and in any case the burned product is not so hard and stony as that from clay. With an organic bond, the product is a charred mass, which is relatively soft, but very tenacious and difficult to remove by mechanical means.

The method which is most suitable for restoring a moulding sand must be varied to suit the nature of the sand. Thus, in a clay-bonded sand free from added organic bond, the useless material is in comparatively large pieces, and most of it can be separated by passing the sand over a pair of suitable screens or sieves (I. 442), such as a 25-mesh and an 80- or 100-mesh sieve respectively.

The reclaimed sand, as well as the waste material, should be subjected to the action of a magnet in order to remove any metallic iron, which would otherwise be lost. A method which may be used for this purpose is described in Vol. I. p. 430.

The coarse material rejected by the 25-mesh sieve may be passed through a disintegrator (I. 352) and reduced to powder and the product screened on the two sieves just mentioned. The material passing the 80- or 100-mesh sieve is usually too fine to be of use for ordinary purposes. Moreover, it contains all the dust and raw clay. The chief disadvantage of this treatment is the removal of the useful clay bond, which has to be replaced by added clay; the latter, however, is seldom so satisfactory as the clay which occurs naturally in the sand. A further drawback is the difficulty of passing the fine material through the 80-mesh sieve, as moulding sands usually behave as if they were slightly damp. This difficulty may be avoided (*a*) by washing the sand and carrying off the fine particles in suspension (but this necessitates drying the sand afterwards), or (*b*) by means of an air-separator; this is usually sufficiently satisfactory, though the separation effected is not so sharp as when the sand is washed.

When the sieving and disintegrating treatment just recommended is regarded as unnecessarily costly, it will sometimes suffice to pass the used sand through a Rapp Revivifier (I. 353), which is very popular in the United States.

When the used sand contains a burnt organic bond, the latter may be loosened by mixing the old sand with the new sharp sand in a rotary drum containing a number of steel balls or pebbles, the drum being rotated slowly so as not to grind the sand too fine. The product is then passed into an air-separator to remove the fine material, which contains most of the loosened and useless decomposed bond. Alternatively, the organic matter may be burned out by blowing the sand through a hot furnace or burner, and afterwards screening it to remove material which is too coarse or too fine to be of service. This method is not really satisfactory, as it requires very careful manipulation and is costly.

A used sand is, of necessity, deficient in bond, so that a further quantity of bond must be added. Fireclay is generally employed on account of its refractoriness; but where this is not of great importance, ferruginous clays may be more suitable.

The difficulty experienced in causing the clay to coat all the grains of sand without making them sticky is very serious, and has never been fully overcome. If both clay and sand are kept dry, the covering of the grains of sand is incomplete; if the clay is made into a slip or slurry and the sand mixed therewith, the product is almost certain to be too sticky. The former method is generally adopted, the dry clay and the sand being tumbled together in a drum or other mixer, or, better still, treated in an edge-runner mill (p. 124).

Various attempts have been made to restore or revivify moulding sands by the addition of chemical substances. Unless these are bonds, they cannot make good the bond destroyed by the use of the sand, and such non-bonding chemicals are therefore of small value.

The customary method of restoring old sand by mixing with it a large proportion of new sand is very imperfect, and cannot be regarded as satisfactory; it is merely a makeshift until better methods are introduced into the foundry, and it is in any case extremely wasteful.

The great disadvantage of applying any method of reclaiming or restoring used sand in British foundries is that in most cases natural sands are used and any extensive reclamation will involve the introduction of artificial mixtures, which are admittedly inferior to the best natural sands. Whether the difference is sufficiently great to be considered is seriously open to doubt, as the few British foundries where reclamation is seriously attempted have benefited greatly by doing so. In the course of time the use of artificial mixtures will become imperative, as the supplies of good natural moulding sands are distinctly limited, and as they are worked out they will have to be replaced by artificial mixtures. It would be a much wiser policy on the part of British foundrymen to reclaim as much spent or used sand as possible, as they would not only effect a considerable saving in their sand-bill, but at the same time they would be gaining experience in the preparation of synthetic sands which will stand them in good stead in future years, when the shortage of natural sands becomes serious.

Testing Moulding Sands.—The principal tests to be applied to moulding sands are the following:

1. *Chemical analysis* (I. 237), including a determination of the moisture present, which is important.

2. *Mineralogical examination* (I. 256), especially as regards the percentage of quartz, clay, and fluxes.

3. A *Sizing or Grading test* (I. 246), to show the proportions of coarse, medium, and fine sand, silt, and clayey matter.

4. A *Microscopical examination* (I. 241), to determine the shape and other properties of the grains and also the nature of the impurities present.

5. *Plasticity or Bond absorption test* (I. 245).

6. A *Refractoriness test* (I. 260).

7. A *Porosity test* (I. 261).

8. A *Permeability test* (I. 263).

9. *Strength tests*, i.e. (a) tensile, (b) crushing, and (c) transverse strength tests (I. 265).

The testing of the strength of moulding sands in the green state (p. 77) is very difficult, especially when the sands are very mild. The determination of the transverse strength is particularly difficult, and as a substitute for it R. C. Lindstrum has suggested that the test bar should measure $1\frac{1}{2}$ in. \times 1 in. \times 1 in., and that it should be slowly pushed along a glass plate until the overhanging portion of the bar is greater than the strength of the material and the bar breaks. Lindstrum has stated that such a bar should not break until it projects at least $2\frac{1}{2}$ in. beyond the edge of the plate.

In some cases it may be desirable to separate the clay or bond

from the sand and to test the strength of the bond. These tests are usually made in the following sized pieces: tensile test on 8-shaped piece with breaking section 1 in. \times 1 in., as used in testing Portland cement; compression test, 2 in. \times 1 in. \times 1 in.; transverse strength test, 4 in. \times 1 in. \times 1 in. between supports. It is usually necessary to ram all the test pieces to a definite density, *e.g.* 1.75. It is desirable that moulding sands should be frequently tested for tensile strength, as this is related to their *plasticity* and *cohesion*, which are most important properties, so that if any sand is becoming unduly weak it may be revived or a new supply of sand added.

10. The *shrinkage on drying* may be of importance in some cases, particularly in loams.

SAND FOR LINING METALLURGICAL FURNACES

Sand is used to a considerable extent for lining the hearths of open-hearth furnaces and cupolas and for the insides of ladles and other articles used at very high temperatures. The properties and use of sand for these purposes are described in the section on *Sands as Refractory Materials* (Chapter VII.).

SAND AS AN INGREDIENT IN METAL MIXTURES

Sand is sometimes used instead of ferrosilicon to introduce silicon to metals; carborundum sand (I. 86) has also been used for this purpose and also for the production of metallic silicides and quaternary steels. The sand should be sufficiently fine to combine readily with the molten metal and sufficiently pure not to introduce undesirable impurities. A white sand containing at least 96 per cent of silica which passes completely through a 50-mesh sieve is usually satisfactory. The shape of the grains is not important.

SAND USED IN SMELTING AND REFINING METALS

Sand is used, to some extent, in the smelting of ores and the refining of metals to combine with any basic materials present and form a slag which rises and leaves the metal comparatively pure. Thus, copper ores, rich in sulphides, are mixed with silica or a siliceous ore to combine with the iron oxide formed when the ore is roasted. In lead smelting, silica is also used for a similar purpose. The conversion of copper mattes in a Bessemer converter is also effected by mixing them with about one quarter to half their weight of quartz.

The sand used for fluxing need not have any special properties, except that it should consist as far as possible of free silica. All the other oxides and minerals present in impure sands are quite useless for fluxing purposes. Hence, the best sand is that which

leaves the smallest residue when heated with hydrofluoric and sulphuric acids. The percentage of silica present is not a reliable guide to the purity of the sand, as silica in the form of felspar, mica, etc., is useless to the smelter and refiner.

The silica may be in the form of quartz, quartzite, or sandstone; the material is crushed to fairly small pieces, but need not necessarily be reduced to powder.

Carborundum sand (I. 86) has also been used as a flux for reducing copper, nickel, and lead from their chlorides.

USE OF SAND FOR WELDING

Sand is sprinkled on the surfaces of pieces of iron to be welded. This forms, with the oxide on the surfaces of the metal, a fusible silicate, $2\text{FeO} \cdot \text{SiO}_2$, which protects them from further oxidation, yet is easily squeezed out when the two pieces are pressed or hammered together. By this means, good metallic contact is produced and a good weld is obtained. Large pieces of metal are sometimes heated in a sand-bed for the same purpose.

The sand used in this way should consist of very small particles, and should be passed through a 50-mesh sieve before use. As only the silica is required, any impurities are objectionable, and the purer the sand the better. No other special qualities are required.

USE OF SAND FOR ENAMELLING METALS

Sand is used in the preparation of enamels applied to metals. These enamels are really glasses, and the sand used in their manufacture should have the same properties as the sand used for making glass. The presence of silica in enamels hardens them and increases their resistance to acids and to heat. An excessive proportion of silica causes the enamel to "chip," whilst with an insufficiency of silica the enamel is very liable to crack with slight changes in temperature.

Fine river or pit sand, small fragments of quartz or flint, or any form of free silica which is sufficiently pure may be used, but the most suitable sands are those used for making white (*i.e.* colourless) glass, though for dark-coloured enamels sands which are rather less pure may be used.

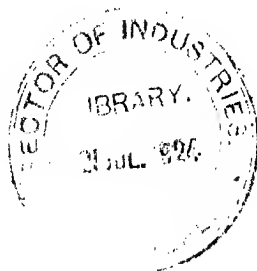
For most enamels the sand should contain 97-99 per cent of silica and not more than 0.33 per cent of iron oxide. A small percentage of alumina, preferably in the form of felspar, is desirable, as it increases the brilliance, hardness, and refractoriness of the enamel and enables it to adhere more firmly to the metal. Unfortunately, alumina renders the molten enamel more viscous, and consequently some difficulty is experienced in pouring it. An excess of alumina is objectionable as it makes the enamel opaque.

Sands to be used for enamelling should be free from clay, for

although it forms one means of introducing alumina it is inferior to felspar. Moreover, it is difficult to find a sand containing a suitable proportion of clay without also containing too much iron oxide, which discolours enamels. It is therefore better to avoid clayey sands in the preparation of enamels.

The presence in the sand of a small proportion of lime, potash, and soda is not objectionable, but the proportion of magnesia should be as low as possible, as it makes the molten enamel viscous.

The shape and size of the grains should be the same as in sands used for glass-making (see Chapter XII.), except that the proportion of rock flour, silt or dust passing through a 200-mesh sieve should not be large, as extremely minute particles of silica rapidly attack the crucibles in which the enamels are melted during their preparation.



CHAPTER VII

THE USES OF SANDS AS REFRACTORY MATERIALS

As previously explained (I. 230), silica, when pure, is a highly refractory material, and consequently has many uses in furnaces and other situations where high temperatures are attained. As a refractory material, sand is used in four ways: (a) as a sand, (b) in the form of bricks or blocks composed of sand or crushed rock, bound together by a suitable agent, such as lime or clay, and used as refractory materials in the construction of the furnaces, etc., (c) as an ingredient in the materials used for certain crucibles, and (d) as a constituent of a refractory cement or "compo."

The principal requirements in sands and crushed rocks which are to be used for refractory purposes are, of course, a high degree of refractoriness (p. 138) and inertness, which are dependent on the chemical composition of the material and on the size and shape of the grains, but other properties must also be taken into consideration, if the best possible product is to be obtained.

SANDS FOR FURNACE LININGS

Sands and crushed rocks are used in various metallurgical furnaces, especially those of the open-hearth type, for the construction of the hearths and the lower parts of the sides of the furnaces. Thus, in the *open-hearth furnaces used for making steel* (Fig. 7), the bottom of hearth is formed on a foundation of brickwork by placing upon the latter a series of layers of siliceous material, the lowest consisting of crushed silica rock, with which a small proportion of sand is mixed, the succeeding layers containing an increasing proportion of sand until the topmost layer consists almost wholly of sand. The material for each layer is placed on the hearth and banked up at the sides in layers about $\frac{1}{2}$ in. thick, until a total thickness of 3 ft. or more is attained. The sides of the hearth are sloped to the "angle of rest" of the sand. The purpose of the sand-hearth is to provide a bottom or basin which will not react seriously with the metal, and yet will absorb any slag left after the removal of each batch of metal. The sides of the hearth or "banks" must be high enough to protect the lower

part of the walls of the furnace and may be regarded as part of the hearth.

When one layer of material has been placed in position its surface is fritted or fused superficially by heating it for about ten minutes to "fix" the sand or "burn it in." As the succeeding layers of sand are heated, and particularly when the furnace is in use, some of the material is converted into the low specific gravity forms of silica, viz., tridymite and cristobalite (I. 226). The conversion takes place to a much greater extent in the sand applied to the sides of the furnace above the level of the molten metal than in the hearth itself, and some of the "sand" on the sides of the furnace may eventually consist chiefly of cristobalite, as the temperature attained (1600° - 1650° C.) is well above the transition point. Below this, tridymite is chiefly formed, the interlocking crystals forming a very strong belt and giving great rigidity to the

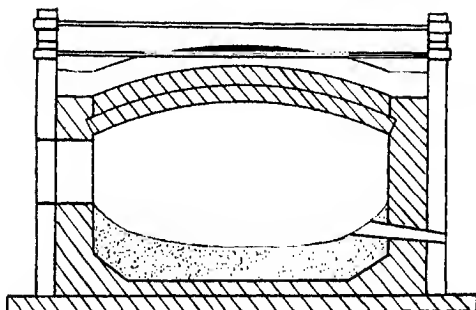


FIG. 7.—Open-hearth furnace.

hearth. The interstices between the silica crystals in both these zones are filled with iron silicate, largely fayalite ($2\text{FeO} \cdot \text{SiO}_2$). Still lower in the hearth, where the temperature is lower and the penetration of the iron is much less, the hearth consists chiefly of unaltered quartz, with occasional traces of tridymite. In some cases the iron penetrates right to the brickwork bottom of the hearth, but this only occurs when there are cracks in the sand.

When a sufficient amount of sand has been placed in position, it is "washed over" with iron slag to fill in the crevices and give a smooth, dense surface to the hearth and sides of the furnace. The slag also accelerates the conversion of the silica to the low specific gravity forms, and it also aids in binding the particles together. When the furnace is in use, iron oxide comes into contact with the sand and further aids in binding together the particles, and in the conversion of the silica. When a hearth is new, it is comparatively porous, but after being washed over with slag, its porosity

is reduced and still more so after it has been used for some time, as the iron penetrates into the sand and renders it, increasingly impervious, so that, as the hearth becomes older, less metal is lost by absorption. Even in a well-built hearth the amount of iron absorbed is considerable, as the upper layers of a hearth after prolonged use may only contain 70 per cent of silica, most of the remainder being silicate of iron. Above the level of the metal the penetration is, of course, less, but is still considerable.

Repairs are usually necessary after each heat; those to the hearth are usually made by dropping sand on to the weak spots and tamping it down, whilst the banks are strengthened by throwing sand on to them. The residual slag on the hearth gradually combines with the new sand thus introduced and securely fastens the particles to each other and to the hearth, so that they form part of it.

Furnaces for malleable iron have hearths made of silica sand, similar to those in open-hearth furnaces.

In *cupolas*, a layer of sand and clay is rammed upon the "bottom doors" to form a sloping hearth about 3 in. deep at the shallowest part, with a slope of about $\frac{3}{4}$ in. per ft. This "hearth" is required to protect the metal doors during the melting of the metal, but it must not bake hard in use, or trouble will occur when it is desired to open the doors. It must, therefore, contain sufficient clay to bind it, but no excess, as that would cause cracks. A clayey sand is largely used for this purpose on the Continent, but most of the cupolas in this country are lined with ground ganister (I. 111), which is tamped into place. In some cupolas, mixtures of clay with other silica rocks are employed, the particles being bound together by the fireclay, and in others an old moulding sand mixed with clay-water is employed.

Sand is also used to form the bottom in *soaking pits* and some *reverberatory furnaces*, for coating the baths which hold the molten metal in *setting furnaces*, for lining the heating chamber of *surface combustion furnaces*, and for sundry other purposes.

The *ladles* used in casting molten steel are often lined with a mixture of sand and fireclay.

In *furnaces for smelting and refining copper*, i.e. the reverberatory or open-hearth types, the hearths are generally made of sand, though in America crushed quartzite or sandstone is more frequently employed for this purpose. The hearth is constructed in a similar manner to those of steel-melting furnaces, except that copper slag is used instead of iron slag to consolidate the sand and form a strong and impervious hearth.

The sand hearth is made in two parts, the first about 12 in. thick and the second layer about 4 in. thick, the latter being replaced when necessary by adding more sand until the thickness of the hearth is inconveniently great. Some furnace men use very little slag in rebuilding the furnace-bottoms, but others apply melted slag after each addition of sand. After applying the last

layer of sand, finely ground slag may be sprinkled around the junction of the bottom to the side walls with a mixture of fireclay and crushed quartzite or sandstone, this final coat being fired for about an hour to harden it properly.

In some American copper furnaces, the hearth consists of a bottom layer of poured slag 2 ft. thick, covered by a layer of broken fire-bricks about 1 ft. thick, which is, in turn, covered with a layer of tamped sand 26 in. thick. The hearth (before adding the last lot of slag to close up the pores in the surface) is carefully fired for six or seven days, after which the final dose of slag is put on and the hearth is again heated superficially to enable it to absorb the slag. The furnace is then charged in the ordinary way, about two weeks' regular use being necessary to saturate fully the upper layers of the hearth. A much larger proportion of slag is used in the hearths of copper-smelting furnaces than in those of steel furnaces, and sometimes oxidised copper scrap or copper scale is put on to the hearth so as to combine with the silica and form cuprous silicate which saturates the upper part of the hearth and gives it an impervious surface. It is sometimes desirable to scatter a high silica sand or ground quartzite upon the hearths of copper furnaces so as to combine with some of the copper and form a slag which will render the surface impervious and thus prevent an excessive loss of copper. In short, the hearth must be maintained highly siliceous to prevent metal penetrating it. However well the hearth is made, some metal will be absorbed, but this can be minimised by the use of a suitable graded sand and by skilled workmanship. The hearths are repaired by dropping sand through holes in the roof on to the corroded parts of the furnace, and where possible, tamping the sand to consolidate it.

The *settlers* used in conjunction with copper reverberatory furnaces are sometimes lined with sand; this is less economical than magnesia, though cheaper in first cost. A damp mixture of crushed quartz and clay is often used as a packing (about 12 in. thick, where chrome bricks are used, but only 4 in. thick if the settlers are lined with silica bricks, as the heat conducted through silica bricks is much less than that through chrome bricks) between the lining and shell of the blast-furnace settlers used in copper smelting. This packing is not subject to any great heat or corrosion, and need not be specially refractory. It is used to act as a cushion to enable the chrome bricks comprising the lining to expand, and it also serves as an insulator, as chrome bricks are fairly good conductors and allow a considerable amount of heat to pass through them. Repairs to settlers in the copper-smelting industry are usually effected by tamping crushed quartz into the corroded or worn part by means of bars.

In *lead*, and *silver furnaces* (*cupelling furnaces*) the lower part of the hearths are often composed of a mixture of sand and clay applied in the form of a damp mass, but not as a paste, the upper surface being made of clay, cement, and bone-ash or magnesia,

siliceous sand as a refractory lining in industrial furnaces, particularly for those used in melting brass and other alloys.

Zirconia and *zircon sands* (I. 168) have also been used for the same purpose, but they are too costly except for very small furnaces.

The properties required in sands to be used for hearths and linings are, mainly, refractoriness and inertness to the metals and slags with which they come in contact. Sands consisting almost wholly of silica are chiefly used, but during recent years other materials such as carborundum, burned moulding sand, etc., have been employed.

The refractoriness of the sand must, naturally, depend on the temperature to which it is likely to be exposed, and this is much greater in a steel-melting furnace than in a copper- or brass-smelting furnace. As, however, the more refractory sands are much safer to use and the difference in cost is not great, it is preferable to employ a sand which has a refractoriness not less than that of Seger cone 33 (1730° C.) for all hearths. In steel-melting furnaces a refractoriness equal to cone 35 (1770° C.) may usually be preferred, as such hearths attain a temperature approaching that of molten steel, namely, 1600°-1650° C., whilst the sides may be nearly 1700° C. At the same time, the sand used for the hearths of furnaces should not be so refractory that it will not fuse superficially to such an extent as just to bind the particles together without causing the material to flow. A sand which is too refractory may easily be "let down" by mixing it with a less refractory sand, and conversely, a sand which is too fusible may sometimes be made satisfactory by the addition of a more refractory sand. The lower part of the hearth need not be so refractory as the upper part, because its temperature is much lower; consequently, it may very conveniently be saturated with iron, provided this is not oxidised, as the metallic iron gives strength to the hearth.

The chemical composition of sands used for furnace hearths, etc., is very important, as it is so closely connected with their refractoriness. For the latter, it is essential that if a siliceous sand is used it should contain as high a percentage as possible of pure silica. Only colourless quartz can safely be used, the coloured varieties being too impure. Crystalline silica must be used where the greatest refractoriness is required, as amorphous forms of silica fuse at a lower temperature. Where the working temperature is not too high, however, amorphous silica is quite satisfactory.

Crystalline silica is available for use as a refractory material in the form of rock crystal, sand, sandstone, quartzites, schists, etc. The forms of crystalline silica which have a low specific gravity, namely, tridymite and cristobalite, are very desirable; they are formed to some extent when silica is raised to high temperatures (I. 226).

The sand used for lining the hearths, etc., of metallurgical furnaces should contain 95-99 per cent of silica; the average of the suitable British sands is, according to Boswell, about 98 per

cent, but the Belgian sands which have so long been used in this country contain about 98·8 per cent, whilst Dutch sands contain about 97·5 per cent.

Furnaces used for copper smelting do not require such refractory sand as steel-melting furnaces, on account of the lower temperature at which copper furnaces are worked; a sand or crushed stone containing 95-97 per cent of silica is suitable; in some cases, a small proportion of flux is added in order to secure the necessary fusibility. A mixture used for lining some copper converters in America consists of siliceous ore and pond slime, and contains only 60-70 per cent of silica, 10-12 per cent of alumina, and 5 per cent of iron oxide!

In Swansea, sea sand containing 88 per cent of silica, 2 per cent of alumina, 2·7 per cent of iron oxide, and 3·8 per cent of lime and magnesia, is sometimes used for the hearths of copper-smelting furnaces, and contains sufficient fluxing material to be used without any further addition.

The *impurities* in sands containing 98 per cent or more of silica (such as those used for the hearths of steel furnaces) must necessarily be small, and a detailed consideration of them is scarcely necessary. In the less pure sands used for copper-smelting furnaces, etc., the impurities are somewhat more important. In both cases, the ones of most importance are clay, fluxes, organic matter, and water.

Clay may or may not be a desirable constituent in open-hearth furnaces; a small quantity may be present with advantage if it is sufficiently pure not to introduce undesirable fluxes into the sand, as it adds to the rigidity and impermeability of the hearth. In some cases, 1 part of brown loamy sand is added to 4 parts of refractory sand to give the latter the necessary fluxing power. The chief objection to clay is that in contact with iron oxide it produces a fluid slag which rapidly cuts into the sand hearth and sides and necessitates frequent repairs. Iron oxide has the same effect on sand, but the particles of sand are so much larger than those of clay that the latter is attacked far more rapidly. Its action, however, is not so serious as that of more fusible alumina compounds, so that a small proportion cannot do much harm to the sand; a large proportion, however, should not be present. It is seldom safe to use a sand containing more than 3 per cent of alumina (which corresponds to 7·5 per cent of clay) for the hearths and banks of steel furnaces, but for furnaces used for smelting other metals at lower temperatures a larger proportion of clay may be present.

Clay is frequently mixed with the sand and, by dropping the mixture into the furnace, is used to repair the furnace hearths and fill up the corroded spots; this process is sometimes known as "claying," a very siliceous clay being used in some works, whilst in others a mixture of sand and clay is employed.

A moderate proportion of clay is very desirable in the sand used for furnace linings other than the hearths, as such sands require

a binding material in order to make them adhere to the structure. The clay may occur naturally in the sand, or it may be deliberately added to a sand or crushed rock. Thus, the natural ganister used for lining converters, crucible furnaces, etc., contains 5-12 per cent of clay as a natural ingredient, which makes the ganister a self-binding material. Where crushed quartz free from clay is used for tamped linings, it may be mixed with 6-25 per cent of fireclay, so as to produce a material which is sufficiently cohesive to be rammed and remain in its place when the form is removed.

Whenever a mixture of clay and sand is used in a furnace, the proportion of clay must not be excessive, or the mixture will shrink unduly and cracks will occur. The best results will be obtained if sufficient clay is present to ensure the necessary binding effect, after which any additional clay is detrimental.

It is most important that the clay used in sand mixtures for furnace work should be highly refractory, as a clay which is less refractory than the sand may cause serious trouble on account of the fusion of the clay during use, which may cause the disintegration of the lining. The clay should, therefore, be at least as refractory as the sand employed; it is also important that it should be as plastic as possible, so as to reduce to a minimum the proportion of clay required to bind the particles of silica or other non-plastic material together. This is desirable, because however pure a clay may be, it introduces very fine particles into the mixture; these are undesirable, as they are so readily attacked by any fluxes present and so increase the proportion of fused material.

Fluxes (I. 184) are undesirable in refractory sands, as they reduce the refractoriness of the material. Not more than 2 per cent in all of lime, magnesia, and alkalis should be present, and a still smaller proportion is found in the best sands. These oxides occur chiefly in the form of *felspar* and *mica*, and whilst felspar is less harmful than mica, neither should be present in appreciable proportions or the sand will be excessively fusible.

Iron compounds always occur to a small extent in sand, but should not exceed the equivalent of 1 per cent of ferric oxide. Ferric oxide or limonite in the form of a film over the surfaces of the sand grains seldom does any harm, but iron sulphide (pyrites) is very objectionable, as it forms a fusible silicate.

The sand composing the hearth or the lower part of the walls of a metal-melting furnace is penetrated by iron oxide or other metallic oxide from the molten metal. This oxide exerts a corrosive influence on it and forms fusible silicates, so that unless the sand is very pure and free from fluxes, an excessive amount of fusion will occur and the hearth or lining will be useless. A hearth in which too much fusion has occurred will have its pores or interstices filled with molten metal and slag, and so will not be sufficiently absorbent to retain the slag and metallic oxide, which is part of its regular work without itself fusing to any great extent. The selection of a suitable sand is rendered all the more difficult in the

case of open-hearth steel furnaces by the fact that the iron oxide is in the ferrous state, and therefore acts as a powerful flux. Fortunately, the purest available sands, when not composed of too small grains, are well suited for the purpose. Crushed ganister or a mixture of a pure silica sand with fireclay may be used when a more plastic material is required.

Organic matter (1. 200) is undesirable in a sand used for furnace hearths or linings, though less than 1 per cent will usually do no harm.

Moisture.—It is important that sands used for hearths and linings of furnaces should be free from moisture, as otherwise much trouble may be caused. When the furnace is heated the hearth or lining may crack, and any steam trapped in the sand may cause explosions and blow out portions of the material, even if it does not in other ways seriously damage the furnace structure. Hence it is very important that all sand used for such purposes should be thoroughly dried before the furnace is used. If a damp mixture of clay and sand or a ganister is used, the furnace should be very carefully and slowly dried so as to remove all moisture before the furnace is charged. It is often necessary to use damp material for lining a furnace, because the necessary adhesion can be secured in no other way; but when the lining or repairing is completed no pains should be spared to ensure that all the moisture is removed from the material by carefully drying those parts of the furnace in which it occurs.

The shape of the grains of sand depends on the purpose for which they are to be used. For furnace hearths they should usually be sub-rounded or sub-angular, approaching to angular. A sand somewhat angular is more satisfactory, as round-grained sands do not stand well on the "banks," because the angle of rest is very low; in open-hearth furnaces the bank must be at a high angle. On the other hand, grains which are too angular do not lie sufficiently compactly to form a mass of minimum porosity for that particular size of grain. This is especially objectionable for the uppermost layers of the hearths, where tamping is often impossible, and the sand is required when thrown on to the bank to assume naturally a minimum porosity and maximum compactness. This is best attained by sub-angular or partly rounded grains. For lining the hearths of copper furnaces, many workers prefer a more angular-grained material, especially in America, where crushed quartzite is largely used, as it gives splintery and angular grains, though the results obtained are not as satisfactory as those with a less angular material. In comparing grains of various shapes the fact must not be overlooked that the size of the grain also plays an important part which is sometimes attributed to the shape of the grains. Thus, large angular grains are more resistant than small sub-angular grains, but the difference lies much more in the effect of their size than that of their shape.

The size of the grains of sand or crushed rock should depend on

the purpose for which they are to be used. In sands used for lining the sides, hearths, etc., of metallurgical furnaces, the grains should not usually be less than 0.004 in. or more than 0.02 in. diameter, though these figures must not be taken too rigidly. Most of the sands used in this country for furnace hearths contain over 95 per cent of grains within these limits, the bulk of the material consisting of grains 0.01 in. and 0.02 in. diameter. Crushed rock is usually coarser than the sand, but if used in a dry state is objectionable to the furnace-men, who find that it does not form a sufficiently dense and smooth hearth. For vertical parts of the lining a coarser mixture can be used, because the clay present enables a better "finish" to be produced. During the War, when more suitable materials were difficult to obtain, a very coarse sand obtained at Haydon Bridge, near Hexham, Northumberland, was used with satisfactory results. This material was examined by Boswell, who found that it contained 37.8 per cent of grains over 0.08 in. diameter, 8.3 per cent between 0.04 in. and 0.08 in. diameter, and 38.2 per cent between 0.004 in. and 0.02 in. diameter. In America, quartz or sandstone crushed to pass completely through a 10-mesh sieve is used for the bottoms of copper-smelting furnaces, whilst in some cases 5-mesh material is also included; these are much coarser than the sands used in Great Britain.

Very fine grains of sand are undesirable, as they have a lower angle of rest, which is inconvenient in open-hearth furnaces, and they are also attacked by fluxes more easily than are coarser grains.

When a hearth is first built or is being rebuilt, the sand used for the lower layers may be suitably graded to some extent so as to secure a maximum density, any remaining interstices being filled with molten slag which is absorbed by the porous sand and binds the whole mass securely together. The sand used for the upper layers and for repairing the hot furnace, on the contrary, should not be graded, but should consist of uniformly-sized particles, because when a mixed sand containing grains of various sizes is thrown on to a hearth without any tamping, such particles of irregular size will not fall in such a manner that the small grains fill the interstices between the larger ones; they are much more likely to separate the large grains and thus increase the porosity. With a sand of uniformly-sized particles, however, this cannot occur, as, however the grains may fall, they will give the maximum compactness possible with such a sand without tamping or shaking down. It is therefore desirable, in repairs, to use sand consisting of particles of uniform size. Where it is possible to tamp the sand in the furnace so as to secure the maximum packing effect, it may be desirable to use a mixed sand, so as to minimise the quantity of pores, but where this is impossible a uniformly-sized sand is preferable.

The Preparation of sands for furnace hearths and linings is described on p. 158.

The **Testing of sands** for furnace hearths and linings may usually be confined to the tests mentioned on p. 160, care being taken to use only those materials whose composition and physical properties are within the limits mentioned on pp. 138-142.

SANDS FOR REFRACTORY SILICA BRICKS

The use and properties of sand for making building bricks have been described in Chapter I., but in addition to these there is a large and important class of bricks used in furnace, kiln, and oven construction and known as "silica fire-bricks" or more often as "silica bricks." Their chief value lies in their great resistance to heat, which enables them to be used in the hottest parts of the furnaces and kilns. For some purposes they are superior to fire-bricks made of fireclay and other refractory materials,¹ especially as they are not unduly costly, are very resistant to corrosion and abrasion, and have a slightly higher thermal conductivity than fireclay bricks. As they expand rather than shrink when in use (as do fireclay bricks), they are particularly useful for the upper parts of furnaces, such as arches, crowns, etc., as bricks which do not contract do not so readily fall from the roof or arch and thus tend to avoid the collapse of the structure. In this respect, silica bricks are particularly useful in glass furnaces, where the fall of fireclay from the roof would contaminate the glass. They are used in furnaces where strength is required at high temperatures, as in gas-fired furnaces and kilns, on account of the fact that silica bricks when heated under a load do not soften gradually as do fireclay bricks, but retain their shape to a high temperature and then fail suddenly. They are also used in reverberatory open-hearth and other metallurgical furnaces in which constructional materials of an acid nature are required.

They have been increasingly used in recent years in the construction of coke ovens, as they have a rather higher thermal conductivity than fireclay bricks, with the result that coal can be distilled rather more rapidly and at a slightly less cost. In addition, they are less readily attacked by the salts in the coal.

The chief disadvantage of silica bricks is that they are unable to withstand sudden changes of temperature; under such conditions they crack and spall, so that they must not be exposed to rapid variations in temperature.

Tridymite bricks are silica bricks in which the whole of the silica has been converted into tridymite; such bricks are constant in volume and do not spall in use. No brick on the market consists entirely of the low specific gravity forms of silica (I. 177), but some contain a large proportion of these materials. Bricks containing a large proportion of tridymite are used for the same purposes as ordinary silica bricks, but they have a greater durability.

¹ See *Refractory Materials: their Manufacture and Uses*, by A. B. Searle (Griffin, London).

Ganister bricks are made from ganister, a natural mixture of siliceous material and clay, which is self-binding on account of the clay present, and so merely needs to be crushed to the required fineness and mixed with water and sometimes a little lime to increase the cohesion of the material. Ganister bricks may be used for practically all the purposes for which silica bricks are employed, but they are more constant in volume on account of the contraction of the clay neutralising some of the expansion of the silica. In some cases, the neutralisation is so exact that the bricks neither expand nor contract in use. Such bricks, however, contain a larger amount of clay than is found in the best ganister and are really semi-silica bricks (p. 145).

Sand bricks are composed of sand to which a suitable quantity of lime is added as a bond. As the raw material is already in the form of powder it does not need to be crushed before making into bricks. The waste sand from glass works has been used for making such bricks, but they are of inferior quality. The disadvantage of sand bricks is that it is very difficult to obtain a raw material in which all the grains are of suitable sizes to make a satisfactory product; where they do so and the sand is sufficiently pure, the bricks are in every respect as good as bricks made by crushing silica rocks. Apart from the small quantities of natural sands formed by the action of the weather on highly siliceous rocks, which may suitably be used for the manufacture of silica fire-bricks, there are other deposits of sand which can be used for this purpose; one of the best known is a loamy sand of a greenish-grey or white colour which occurs in deposits up to 5 ft. thick at Ewell, Epsom, and Chalfont St. Peters, Bucks (l. 69), from which the *Ewell bricks* are made. These bricks are red in colour, due to the proportion of iron oxide present, and are quite soft, so that they can readily be sawn or carved to any desired shape. They need to be handled with care, and are only moderately refractory on account of the large proportion of fluxes present, yet they are used extensively in the south of England for domestic fireplaces, the cooler parts of furnaces, boiler and retort settings, etc. They are specially valuable where it is necessary to cut the bricks to a special shape.

Flint bricks are made from flint which has been crushed to a suitable size and mixed with the required proportion of lime to bind the particles together. Such bricks are of inferior quality, owing to the great expansion which they undergo when heated if raw flint is used; and where the flint is calcined before use, it is difficult to make a brick which is sufficiently strong. Flint bricks should only be employed where the conditions are not stringent, or where bricks made of extremely small particles of silica are required. A small proportion of finely-ground flint added to the crushed rock or sand used for silica fire-bricks is often an advantage.

Flint-clay bricks are a variety of semi-silica bricks which are

made in America. They are used for lining furnaces, kilns, and other structures where refractoriness and constancy in volume are necessary. They contain no flint, but are made of a hard flint-clay and a softer binding clay.

Besides silica bricks, composed of almost pure silica with a little added lime, there are various other kinds of bricks which consist partly of sand or crushed rock and partly of clay or other material. The chief of these bricks are given below.

Semi-silica bricks consist of sand, ganister, or crushed silica rock and fireclay in various proportions. Such bricks are less refractory than silica bricks, but they are constant in volume when heated, as the contraction of the clay and the expansion of the silica neutralise each other, and this property makes them very useful for the arches and crowns of coke ovens and flues. They are also used for the upper parts of cupolas, crucible furnaces, and for the soles of coke ovens. They are satisfactory substitutes for fireclay bricks in many cases where their special advantage of constant volume is required.

Sand-bauxite bricks consist of a mixture of sand and bauxite together with a suitable quantity of plastic clay as a binder. Such bricks have been found quite satisfactory for furnace linings, but on the whole their use is undesirable, as when heated the sand expands, the clay contracts, and the bauxite (if properly calcined) remains unchanged, so that strains are set up which tend to cause cracks in the bricks and finally lead to their destruction.

Kieselguhr bricks are made by mixing diatomaceous earth or kieselguhr (I. 96) with fireclay; they have only about one-third the weight of ordinary bricks, and in some cases they are so light as to weigh less than an equal volume of water.

Kieselguhr bricks are fairly refractory and are able to withstand high temperatures, but they cannot be used for furnace linings as they do not resist abrasion and corrosion, but must be protected by a lining of some other refractory material. Their special value is in their porosity, which renders them very effective as insulators. They are therefore largely used as an intermediary between the lining and the casing of furnaces, to prevent loss of heat by radiation.

Silica bricks for furnace and kiln construction are made chiefly of crushed silica rock, containing about 98 per cent of silica, but angular sands of the same composition may also be used. The particles must be carefully graded and then mixed with milk of lime or fireclay and water, so as to form a paste which is moulded into bricks; the latter are then dried and afterwards burned at 1400°-1500° C. A prolonged heating at 1400° C. or above is desirable so as to convert the greatest possible proportion of quartz into tridymite and cristobalite (I. 226).

Sources of Sand for Silica Fire-bricks.—Only a few sands and silica rocks are suitable for the manufacture of silica bricks, as the rest are not sufficiently pure. The following may be used if carefully selected; they are mentioned in order of suitability:

Chalcedony, Tertiary erratic quartzite boulders (findings-quartzite), ganister, massive rocks consisting of almost pure quartz or quartzite, quartzites from vein quartz, flint, chert, schistose-quartz, sandstone, sand. The use of sandstone and sand is generally undesirable, as these materials are seldom sufficiently pure and the products are usually of inferior quality. Only the first four rocks and certain quartzites, with the sands derived from them either naturally or by crushing, are really suitable for the manufacture of refractory silica bricks; where possible, these only should be employed, the others being regarded as possible substitutes when better materials are not available.

Semi-silica bricks are made of natural or artificial mixtures of sand or crushed rock and clay; the former include some ganisters (I. 104), the kaolin-bearing sands of Devon and Cornwall which are left after removing the kaolin from decomposed granite (I. 91). Certain glacial sands (I. 115) and the pocket sands which occur in hollows in the Carboniferous Limestone of Derbyshire are used to make silica fire-bricks; those made of the last named are extensively used for coke ovens.

Many sands and other siliceous materials are not suitable, partly on account of their chemical composition and partly because they do not possess the requisite physical properties. This is dealt with later under the captions: Chemical Composition, Specific Gravity, Refractoriness, and Shape and Size of the Grains.

Where an almost pure silica rock has been broken down by the weather and forms a sand, it may be preferable to the original rock, as some slight purification may have been effected. On the other hand, it is often much easier to obtain grains of the requisite sizes when a rock is crushed or ground and then screened, than it is to use a natural sand from the same rock, many of the grains of which may not be suitable for the use of the brick manufacturer. Apart from this, the crushed rock and natural sand are alike suitable.

The geographical distribution of siliceous materials suitable for the manufacture of silica fire-bricks has been fully described in Vol. I. Chapter III. (see *Silica Rocks*), from which it will be found that the best materials in this country are (a) ganister (I. 104), which consists of particles usually from 0.004 in. to 0.012 in. diameter, and (b) the pure silica rocks consisting of grains of about the same size, including the silica rocks of Durham, Yorkshire, Derbyshire, and the Midlands, and some of the quartzites of North and South Wales. The Lickey Quartzites and the Crowstones of Cheshire, as well as some of the Cumberland silica rocks, are somewhat coarser and may consist of particles up to 0.032 in. diameter, whilst rocks which are only suitable for inferior bricks may contain particles over 0.04 in.; these are not really suitable and should be avoided wherever possible.

Rocks which consist of large interlocking crystals of quartz are generally unsuitable, but where the crystals are small and are

enclosed in a glassy ground-mass, the rocks are usually quite suitable; those which consist of the finest individual grains cemented to form larger ones may be employed for very stringent conditions, such as occur in electric and some metallurgical furnaces, whilst the coarser-grained materials may be used for glass furnaces, coke ovens, regenerators, annealing furnaces, etc.

The chemical composition of the sands and crushed rocks used is of considerable importance. A fairly pure silica is desirable, but it need not be perfectly pure, the best silica fire-bricks being made from materials containing 96-98 per cent of silica and about 2-4 per cent of other oxides as impurities. Some gneisses which contain less than 90 per cent of silica make excellent bricks, so that the actual proportion of silica is not of the greatest importance, provided the proportion of fluxes is sufficiently low. Some of the sandstones used for making refractory silica bricks contain as low as 80 per cent of silica and more than 5 per cent of fluxes, etc., but these materials form an inferior product. The proportion of silica varies so greatly that no very definite limits can usefully be laid down with regard to it, though for the most refractory bricks as high a percentage of silica as possible is desirable. The importance of the proportion of other oxides present depends upon their composition; lime, magnesia, soda, and potash are all objectionable, as they reduce the refractoriness of the bricks, though they may increase their strength and resistance to abrasion and corrosion. The total amount of lime, magnesia, potash, and soda in the sand or crushed rock should not usually exceed 2 per cent, though for some purposes the presence of 4 per cent has not been found objectionable.

Fluxes (I. 184) are present in all natural siliceous materials, but the proportion should be as low as possible, otherwise the refractoriness of the material would be unduly reduced.

The presence of a limited amount of *iron oxide* in the raw material is an advantage, as it is an excellent bond, and iron compounds are sometimes added to siliceous materials in order to bind the particles together. Silica rocks containing up to 8 per cent of iron oxide have been used quite satisfactorily. F. H. Brooke and T. Twynan in 1918 suggested the addition of $\frac{1}{2}$ to 3 per cent of fine flue dust (containing a large proportion of magnetic iron oxide) as a binder for silica bricks. The total proportion of iron compounds expressed as ferric oxide should not, in most cases, exceed 2 per cent, and a much smaller percentage is desirable if the bricks are to be used under reducing conditions.

Organic matter and *dirt* should not be present. If any appreciable proportion occurs, the sand must be washed before use.

The proportion of *alumina* present in sands and crushed rocks suitable for making silica fire-bricks varies considerably. If in the form of feldspar and mica, it is objectionable, as these materials are not refractory and act as fluxes (I. 184), but if present as clay a moderate percentage of alumina may be advantageous.

Clay is present to a variable extent in materials suitable for the manufacture of silica fire-bricks; some quartzites contain practically none, whilst others and ganisters may contain 10 per cent or even more. The presence of clay is an advantage in some respects, as it assists in binding together the particles of non-plastic material and reduces the amount of lime necessary to produce an effective bond, some ganisters being self-binding as a result of the clay they contain. Another advantage possessed by clay is that, on account of its contraction, it neutralises to some extent the expansion of the silica and so produces bricks which are much more constant in volume and much less sensitive to sudden changes of temperature than those made of silica and containing no clay. This is one reason why ganister and semi-silica bricks are often preferred to silica bricks, the expansion of which is sometimes troublesome. On the other hand, clay has the disadvantage of reducing the refractoriness of the silica (1. 183), its presence to an extent represented by 5 per cent of alumina lowering the refractoriness of silica by 2 cones or 40° C., whilst clay equivalent to 10 per cent of alumina reduces the refractoriness from cone 35 to cone 27, i.e. from 1770° to 1610° C. This is not, however, so serious a practical drawback as it might seem at first sight, as the mixture of silica and clay, which has the lowest refractoriness, is nevertheless the one which corresponds to the average composition of ganister. Ganister is one of the most valuable materials for the manufacture of silica fire-bricks.

Thus it will be seen that whilst clay may be deleterious as regards refractoriness, it has its value, and under certain conditions its presence is actually desirable. A relatively large percentage of clay is allowable where the bricks are not required to withstand the highest temperatures; for instance, in boiler-settings, hardening and annealing furnaces, retort settings, puddling furnaces, etc.

No matter whether the clay occurs in the siliceous material itself or is added to it, it is important that it should be sufficiently refractory. (See also p. 139, *Clay in Sands for Hearths*.) A fusible clay would unduly reduce the refractoriness of any siliceous material to which it is added. Hence the clay should be sufficiently free from fluxes not to increase the proportion of these constituents in the mixture and should not contain more than about 5 per cent of fluxing oxides.

The impurities in the sand or crushed rock have been described above. They should be finely divided and disseminated uniformly through the mass. Where large particles of impurity occur, trouble may arise which would be less serious if the material were in small pieces.

The chemical composition of the material to be used for silica bricks should not be considered exclusively, as a very pure silica may be quite unsuitable for use, whilst a less pure one may produce very satisfactory bricks.

Refractoriness.—The sand or crushed rock should have a

refractoriness not less than that of cone 33 (1730° C.), though this must not be taken as a fixed rule, as bricks which have a much lower refractoriness may be used with complete satisfaction where the requirements are not so stringent. The refractoriness chiefly depends on the proportion of clay and fluxes present; this has been fully discussed under *Chemical Composition* (p. 147). The refractoriness must not be taken alone, as some sands and silica rocks which have a high refractoriness are unsuitable for making silica fire-bricks, whilst others with a lower refractoriness are, on account of some other properties, particularly valuable.

Specific Gravity.—In making silica bricks, the specific gravity of the sand or crushed rock is very important. As previously explained (I. 226), quartz is converted on heating into other forms of silica with a low specific gravity and there is consequently an increase in the volume of the material which may be serious when the bricks are in use, so that it is desirable that sand or crushed rock should be used which, on heating, will rapidly attain a maximum expansion and after that remain fairly constant in volume. For this reason, some amorphous forms of silica, such as flint, chalcedony, etc., and others which contain a noteworthy proportion of colloidal silica, are specially useful, whilst crystalline quartz is less easily and far more slowly converted. The findings-quartzites or erratic boulder silica rocks are preferable to other forms of quartz because the silica in them is more readily convertible into tridymite or cristobalite. As these rocks are not readily available, other quartzite rocks and sands form the chief source of silica for silica bricks.

A good test of the probable suitability of a silica rock or sand consists in heating it to a temperature of 1450° C., and maintaining it at that temperature for four hours; the material which, when cool, has not disintegrated and also has the lowest specific gravity will be the most satisfactory, as the greatest conversion to tridymite or cristobalite has taken place in it.

The shape of the particles of silica is very important and may make all the difference between good and useless bricks. The grains should be sharp and angular, so that they will interlock with each other and produce a strong mass. It is most important that the grains should not be rounded or they will not bond together properly when the binding material is added. Ganister is very valuable on account of the angular and splintery particles it produces when crushed; these interlock very closely and so form first-class bricks.

One difficulty in the use of natural sand as a material for making silica bricks is the comparative rareness of sands of the desired purity having angular particles which interlock readily. For this reason common sand can seldom be used, but the sands obtained as waste material from china clay pits and the pocket sands of Derbyshire and elsewhere, which are highly angular, are quite satisfactory.

Calced flint, chert, etc., when quenched in water to render crushing easier, do not as a rule form angular particles, with the result that the grains do not bind properly.

Almost the only materials which give grains of suitable size and shape are crushed silica rocks. These break with a splintery fracture and form highly angular particles which interlock readily.

The size of the grains is very important, as two factors are introduced, namely (a) the size of the grains of silica in the sand or rock, and (b) the sizes of the pieces produced by crushing the rock. These factors must be remembered, because the crushing does not liberate every individual grain but produces pieces consisting of a number of grains cemented together. The size of the pieces produced by crushing or grinding may vary from $\frac{1}{4}$ in. diameter down to dust, and these various sizes should be combined in such proportions as to produce bricks of any desired density. Thus, for a porous brick required to resist changes in temperature, a fairly large proportion of large or medium grains may be present, but for a dense brick a large proportion of smaller grains may be used. No grains larger than $\frac{1}{4}$ in. diameter should ever be present, otherwise they will crack and fly on heating and so disintegrate the bricks. On the other hand, the grains must not be too small or the bricks will be too dense and so be unduly sensitive to sudden changes in temperature.

No matter whether a natural sand or a crushed rock is used, the particles should be properly screened and graded so as to consist of grains of different sizes, the smaller particles filling the interstices between the larger ones, and so forming a sufficiently dense and strong mass (Fig. 9) and reducing the amount of binding material necessary. Where the grains are of uniform size they do not interlock so well, and a large amount of bond would be required to cause the particles to adhere, or smaller grains from another source must be added. As only about 2 per cent of lime is allowable for the bond in the best silica bricks, it is important that the grading should be such as to give the maximum strength with this amount of bond.

The size of the individual grains is of great importance. If they are very large they will crack on heating, so it is necessary that they should be sufficiently small. Material composed of the finest individual grains will be more constant in volume, will attain a maximum expansion more quickly, and will be less likely to spall in use. For this reason, such materials should be used for resisting the most stringent conditions as to refractoriness and constancy in volume. Where sudden changes in temperature are to be withstood, the grains should be of medium size (0.02-0.01 in. diameter), so as to produce more porous bricks. One reason why sands can seldom be used for making silica fire-bricks is that the grading is unsuitable; many of the grains are usually too coarse to give the best results (as they are too slowly converted into cristobalite and tridymite), whilst the use of a sand which contains sufficient fine grains would give too dense a brick. These objections are avoided

by the use of a rock consisting of minute particles cemented together by a natural bond, so that when it is crushed each of the particles of the required sizes consists of a number of minute grains cemented together. By this means, conversion of quartz into cristobalite and tridymite is readily effected, as the grains of quartz, although actually small, are yet so combined to form larger grains that the advantages of a well-graded material are obtained. Such a constitution is, of course, impossible with sand, so that bricks made of natural sand are usually less satisfactory than those made of crushed rock. Where a suitably graded, pure sand composed of grains which do not disintegrate on heating can be obtained, it will usually produce good bricks.

Erratic boulders (findlings-quartzites) which occur in Germany have this desirable structure; the grains are very minute and are cemented by means of interstitial colloidal silica.

According to Le Chatelier, any quartzite may be used, provided it is ground to a sufficiently fine state, but the cost of such treatment would often be excessive, and the bricks would usually be extremely sensitive to sudden changes in temperature. Where no really suitable rock material is available, however, a less suitable one will often, if sufficiently finely ground, enable fairly satisfactory bricks to be made.

The Preparation of sands for refractory bricks is described on p. 158.

The Testing of sands and crushed rocks for use in the manufacture of silica fire-bricks may usually be confined to the tests mentioned on p. 160, care being taken to use only those materials which conform in composition and physical properties to the limits mentioned on pp. 147-151. When a silica rock is crushed, the "sand" produced should have the properties just mentioned; methods of testing rocks prior to crushing are described on p. 160.

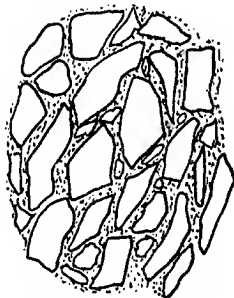


Fig. 9.—Micro-structure of silica brick.

SANDS FOR OTHER REFRACTORY BRICKS

Zirconia and Zircon sands have been used for making suitable refractory bricks, but up to the present time they have not been developed to a very great extent, chiefly because of their cost and the difficulty of obtaining a really suitable bond. Possibly in the future a satisfactory bond (other than colloidal zirconia or a better method of preparing this substance) will be found, after which the use of zirconia bricks appears likely to extend rapidly. Most of the failures hitherto experienced with zirconia bricks are due to the use of too crude a material and a poor bond.

Artificial sands, chiefly carborundum and other carbides (I. 86) and corundum (I. 93), are sometimes used, where great refractoriness is required. Corundum bricks are specially valuable for use at exceptionally high temperatures such as are attained in electric furnaces, as they have practically no shrinkage, a very high refractoriness, and a great resistance to abrasion and corrosion.

These sands should be reduced to particles of the same sizes as those used in the manufacture of silica bricks, and are bonded with clay or, occasionally, with an organic bond such as glue, heavy mineral oil, tar, resin, or glycerine.

SANDS FOR REFRACTORY HOLLOW-WARE

The term "refractory hollow-ware" includes crucibles, muffles, some vessels used in cooking and known as "fireproof ware," saggers, in which the pottery is fired, retorts, etc. Each of these articles is essentially a container in which some material or mixture of various materials is heated, the temperature varying from about 150° C. in the case of domestic ware to 1600° C. in the case of some crucibles. The manufacture of these articles is described in detail in the author's *Refractory Materials: their Manufacture and Uses*,¹ and in the present chapter it is only necessary to refer to the use of sand in their production.

Crucibles are used for heating small quantities of material, usually either to melt it or to enable some desirable chemical reaction to take place, such as the reduction of a metal from concentrated ore or the production of an alloy. Crucibles are of all sizes, from that of a thimble to those which hold 200 lb. of material.

The crucibles in the production of which sand is employed are chiefly composed of a mixture of sand and fireclay which is made into a plastic paste with water and then shaped, dried, and burned in a kiln. Among the best-known crucibles made of such materials are *Hessian crucibles*, which have long been used in the smelting of gold, silver, and other precious metals, and which are composed of a mixture of fireclay and sand in the proportions of two parts of clay to four or five parts of sand, and *Cornish crucibles*, which are used for copper assaying and general experimental work; these are usually composed of two parts of ball clay and two parts of sand from St. Agnes' Beacon or its equivalent, together with a little china clay in some cases. Other crucibles sold under a registered name or one which is supposed to indicate their place of origin are also made of fireclay and sand, the proportions differing according to the purpose for which the crucibles are to be used. Other uses of sand in crucibles include that of the waste sand from glass-works, the use, patented by I. Schlossberg in 1913, of 93 per cent of crushed quartzite with 2 per cent of colloidal silica and $4\frac{1}{2}$ per cent of lime

¹ See footnote on p. 143.

for refractory acid-proof crucibles, and the use of about 5 per cent of sand in graphite or plumbago crucibles, employed for making mild steel, copper alloys, etc.

Crucibles have also been lined with sand and a suitable binding material. J. B. Sidebottom in 1915 patented the use of sand with 6 per cent of ganister, whilst New and Thomas in 1879 patented a mixture of flint and fireclay.

The sand chiefly used in the manufacture of crucibles consists of almost pure quartz in grains not more than 0.02 in. diameter. The size and shape of the grains are not usually of great importance, though "dust" and very coarse particles should usually be removed by screening. Where crucibles are required to withstand high temperatures and the corrosive action of their contents, the sand should not contain more than 3 per cent of metallic oxides. A sand composed of sub-angular grains is usually to be preferred. Any of the sands mentioned on p. 146 may be used for crucibles, provided they conform to the requirements just mentioned and the individual particles do not crack or disintegrate when heated rapidly to about 1400° C.; this last proviso is important.

In addition to siliceous sands, certain non-siliceous sands are used in the manufacture of crucibles. The chief of these are:

Zircon sands, which are specially valuable for very high temperature work on account of their great refractoriness, very low and almost negligible coefficient of expansion, low thermal conductivity, and great resistance to abrasion and corrosion (see p. 151).

Corundum, which consists of bauxite which has been fused in an electric furnace, cooled, allowed to crystallise, and afterwards purified by chemical treatment (l. 94). This material when crushed forms an artificial sand the particles of which are bonded together with clay, cement, plaster of Paris, or a temporary bond such as dextrin, tar, or paraffin to form crucibles and other refractory articles.

Silicon carbide (carborundum) and carboxides, which are composed of silicon and carbon (together with oxygen in the case of carboxides) obtained by fusing in an electric furnace (l. 86). The products are crushed and form an artificial sand which is bonded with water-glass, clay, glue, tar, or other binding material and shaped into crucibles, muffles, saggars, retorts, glass pots, etc. They are valuable on account of their refractoriness, high thermal conductivity, and high electrical conductivity.

Various other crushed rocks which do not consist of silica, but are used in the manufacture of crucibles, are magnesite, dolomite, lime, basic slag, bauxite, graphite, coke, chromite, and iron ore. These, however, hardly come within the compass of this volume, though in one sense they might be classed as sands (see Vol. I. p. 1). All these materials should consist of sub-angular grains, the sizes of which must be selected according to the purposes for which the crucibles are to be used. For most purposes they should pass completely through an aperture $\frac{1}{8}$ in. diameter, but not through

a 50-mesh sieve. Where great resistance to corrosion is required, much smaller particles may sometimes be used with advantage, though "dust" should generally be avoided. The coarser the "sand" within the limits mentioned, the greater will be the resistance of the individual particles to corrosion, but as the corrosive material penetrates more easily a mass composed of coarse particles, it is often better to use a "sand" composed of smaller particles.

Fused sand is used for the manufacture of crucibles and other refractory hollow-ware, particularly for use in the chemical industries and in chemical laboratories, and as an electrical insulator for pyrometer tubes, etc., at high temperatures. As fused silica has many of the properties of glass, it is referred to more fully in Chapter XII.

Muffles are chambers or containers in which various articles are heated to redness out of contact with flame. The heat is usually applied externally, the muffle being placed inside a furnace. They are made of the same materials as crucibles, which in many respects they greatly resemble, although they are different in shape. (See *Crucibles*.)

Fireproof ware is used in domestic cookery because it can be placed directly on a fire without being damaged. It is made of a mixture of fireclay or other refractory clay and fine white sand which need not be highly refractory. Apart from this, such sand should have the same properties as that used for crucibles.

Saggers are rough boxes or cases in which pottery is placed in order that it may be fired in a kiln or oven. They are best made of a refractory clay or grog, but a little sand is sometimes used, though by no means a desirable addition. The most suitable sand for the purpose is a highly refractory and comparatively coarse one which should contain no particles which will pass through a 30-mesh sieve. It should not contain more than about 5 per cent of metallic oxides.

Retorts for the manufacture of coal-gas and for zinc are chiefly made of fireclay and grog, but some makers include a little sand in the mixture. For this purpose the sand should be similar to that suitable for saggers. Carborundum, corundum, zirconia, and other non-siliceous sands used for crucibles (p. 153) are also used for retorts.

SAND FOR REFRACTORY CEMENTS, MORTARS, AND PAINTS

Refractory cements and mortars are employed for binding together the bricks, etc., used in the construction of furnaces, for repairing corroded crucibles, patching, plastering the surface of brickwork, and in the form of a paint for washing over refractory brickwork, etc., to render it more refractory or to give a special resistance to some particular influence, such as corrosion or abrasion.

Refractory cements, mortars, paints, etc., may be divided into

for refractory acid-proof crucibles, and the use of about 5 per cent of sand in graphite or plumbago crucibles, employed for making mild steel, copper alloys, etc.

Crucibles have also been lined with sand and a suitable binding material. J. B. Sidebottom in 1915 patented the use of sand with 6 per cent of ganister, whilst New and Thomas in 1879 patented a mixture of flint and fireclay.

The sand chiefly used in the manufacture of crucibles consists of almost pure quartz in grains not more than 0.02 in. diameter. The size and shape of the grains are not usually of great importance, though "dust" and very coarse particles should usually be removed by screening. Where crucibles are required to withstand high temperatures and the corrosive action of their contents, the sand should not contain more than 3 per cent of metallic oxides. A sand composed of sub-angular grains is usually to be preferred. Any of the sands mentioned on p. 146 may be used for crucibles, provided they conform to the requirements just mentioned and the individual particles do not crack or disintegrate when heated rapidly to about 1400° C.; this last proviso is important.

In addition to siliceous sands, certain non-siliceous sands are used in the manufacture of crucibles. The chief of these are:

Zircon sands, which are specially valuable for very high temperature work on account of their great refractoriness, very low and almost negligible coefficient of expansion, low thermal conductivity, and great resistance to abrasion and corrosion (see p. 151).

Corundum, which consists of bauxite which has been fused in an electric furnace, cooled, allowed to crystallise, and afterwards purified by chemical treatment (l. 94). This material when crushed forms an artificial sand the particles of which are bonded together with clay, cement, plaster of Paris, or a temporary bond such as dextrin, tar, or paraffin to form crucibles and other refractory articles.

Silicon carbide (carborundum) and carboxides, which are composed of silicon and carbon (together with oxygen in the case of carboxides) obtained by fusing in an electric furnace (l. 86). The products are crushed and form an artificial sand which is bonded with water-glass, clay, glue, tar, or other binding material and shaped into crucibles, muffles, saggars, retorts, glass pots, etc. They are valuable on account of their refractoriness, high thermal conductivity, and high electrical conductivity.

Various other crushed rocks which do not consist of silica, but are used in the manufacture of crucibles, are magnesite, dolomite, lime, basic slag, bauxite, graphite, coke, chromite, and iron ore. These, however, hardly come within the compass of this volume, though in one sense they might be classed as sands (see Vol. I. p. 1). All these materials should consist of sub-angular grains, the sizes of which must be selected according to the purposes for which the crucibles are to be used. For most purposes they should pass completely through an aperture $\frac{1}{8}$ in. diameter, but not through

Other mixtures too numerous to specify in detail contain 50 per cent or more of sand, crushed silica rock or silica bricks, the remaining constituents being clay with a very variable proportion of other ingredients, most of which are of very doubtful value. Some of the latter merely act as diluents, whilst others, such as hair or fibrous material, are useful until the cement is heated, after which they usually burn away and leave objectionable pores in the material. The addition of long-fibre asbestos is sometimes useful as a binder, as it is not destroyed at temperatures below 1300° C.

Puramachos is an artificial mixture consisting of powdered quartz with 10 per cent of fireclay and a little water-glass. Various cements which are similar in composition are sold under fancy names.

The *ganister compositions* or *compos* which are so largely used in connection with furnace linings are mixtures of crushed ganister or other silica rock with fireclay. When dry, they usually contain about 10 per cent of coarse silica particles more than $\frac{1}{8}$ in. diameter, about 60 per cent of silica particles between $\frac{1}{8}$ in. and 0.004 in., and 30 per cent of still smaller particles, about half of these being clay. Compos supplied by different firms vary greatly owing to the absence of careful screening and grading of the crushed rock.

4. Mixtures of sand or crushed rocks with a special bond. Most of these are not of great importance, but one useful cement consists of a mixture of fine sand with 10 per cent of magnesium chloride syrup and is used in the form of a putty. This is excellent, provided the temperature to which it is exposed when in use is not greatly above 1300° C.

Silica cements of the types mentioned should contain 83-95 per cent of silica, 90 per cent being a rough average. The proportion of clay may vary from 1 to 12 per cent, whilst other materials may be present in proportions from 2 to 16 per cent. Such silica cements should have a refractoriness at least equal to that of cone 26 and preferably to that of cone 32.

The shrinkage which silica cements undergo in use is important, as the cement will crack if the shrinkage is excessive. The shrinkage on drying will depend chiefly on the clay present; according to R. J. Montgomery it should not be more than 2 per cent and should be preferably about $1\frac{1}{2}$ per cent. Silica cements usually have a porosity of 30-35 per cent when dry; this is reduced in use to 15-30 per cent, according to the composition of the cement and the temperature to which it is heated.

The grains of sand or crushed silica rock should be sub-angular and moderately coarse unless a smooth finish is required, when finer grains will have to be used. For most purposes, the grains should be within the limits of size recommended for ganister (see above).

Other refractory cements containing silica in some form, but in which silica is not the essential constituent, are very numerous.

Most of them resemble the cements just mentioned, but contain a much smaller percentage of silica. For instance, sand is sometimes mixed with fireclay in proportions up to 50 per cent of sand so as to produce refractory cements, which are very constant in volume. Others contain much less silica, like a much-used daub for cupolas and for mending the lining of other furnaces, which consists of a mixture of 20-25 per cent of silica sand and 80-75 per cent of fireclay.

Small quantities of sand are also used in various other refractory cements, but the sand is then only of slight importance, and is chiefly used as a cheap filler.

Powdered zirconia (p. 151) and *zircon sands* (I. 198) are used as cement merely by mixing either of these materials with a suitable amount of water. They are devoid of plasticity and adhesion, and when these properties are required, a suitable bond must be added (see p. 151). Zirconium compounds are chiefly of value on account of their high refractoriness. They are by no means easy to use, as cements and almost all bonds which will withstand high temperatures seriously reduce the refractoriness of the zirconium compounds. The use of colloidal zirconium hydroxide is free from this objection, but its preparation is difficult, and when prepared it is so sensitive to impurities in the zirconia or zircon particles it is required to unite, that it is by no means satisfactory. There is ample scope for much investigation on the production of a really good zirconia cement.

Artificial sands are used to a considerable extent in refractory cements in conjunction with other materials. The principal of these are carbides and corundum.

Carborundum sand is used in refractory cements in combination with fireclay or water-glass or both. A mixture of carborundum fire-sand and fireclay has been extensively used both as a "mortar" and also as a facing or lining material. The precise proportions must necessarily depend on the size of the carborundum particles and on the binding power of the clay.

The following mixtures were patented in 1904 by L. E. Muller : Carborundum 60-90 parts, fireclay 10-40 parts, water-glass 20-50 parts, and lime 0-4 parts. For patching fire-brick linings, especially in brass and steel furnaces, in reverberatory furnaces for copper smelting, and in converters, a mixture of equal parts of carborundum, fire-sand, and fireclay or china clay is particularly useful.

The following mixtures have been used for repairing retorts :

Carborundum sand	3	6	1 parts.
Fireclay	1	1	1 part.

In some cases silica sand and powdered glass is also added, as in the following cement which is commonly used in America for repairing pots for melting glass : Carborundum 1 part, fire-clay 2 parts, white sand 1 part, and powdered glass 1 part.

Other clays, such as ball clay, may sometimes be substituted

for the fireclay, whilst if sufficient water-glass of good quality is used, the clay may be omitted where the temperature is not very great and the carborundum partially replaced by common white sand, as in A, which is used for general patches and repairs, and B, which has been used for lining iron vessels which are constantly kept hot.

	A.	B.
Carborundum	2	3 parts.
Sand	1	"
Water-glass	2	2 "

Carborundum sand in combination with some suitable binding agent is also used as a *furnace paint*. At the Royal Mint a mixture of carborundum sand and water-glass alone is used. Another mixture consists of 65 parts of carborundum, 20 parts of fireclay, 13 parts of water-glass of specific gravity 1.26, and sufficient water to form a paste. This mixture has been found very satisfactory in boiler furnaces, pottery kilns, annealing and other metal furnaces, oil-fired furnaces, and for protecting the melting zone in cupolas.

Siloxicon (I. 90) has been used as a refractory cement in combination with water-glass or tar.

Fused alumina (I. 94) in the form of a "sand" mixed with a small proportion of fireclay has been used as a cement for articles such as snuffles, cores, etc., made of alundum or corundum. It is specially useful where a cement having a high thermal conductivity is required.

The nature of the sand or crushed rock used for refractory cements is, in general, the same as that for ordinary cements (see Chapter III.), but as refractory cements are used at high temperatures the sand must be sufficiently refractory and, therefore, contain a minimum proportion of fluxes. Hence it is desirable to use a sand suitable for furnace linings (p. 132) or crucibles (p. 152). The materials used in refractory cements for binding bricks, patching, etc., are generally ground so as to pass completely through a 40-mesh sieve, as coarse cements do not give such satisfactory results. Where thick layers of cement for lining furnaces are used, as in the case of ganister compos, coarser particles are employed (see p. 142). Zirconia cements are preferably ground to pass a 60-mesh, and a small proportion should be in the colloidal state. Podszus and some other investigators grind the zirconia so that it will all pass through a 200-mesh sieve.

PREPARATION OF SANDS FOR REFRACTORY PURPOSES

Little purification of the sand is usually necessary. If it contains any undue proportion of impurities, dirt, roots, etc., some of these may be removed by *washing* (I. 384), but where possible, it is desirable to use a sand which requires no treatment.

Crushing.—When the sand is prepared from rocks or other massive material, it is necessary to crush and grind them so as to

reduce the particles to the desired sizes. This is effected first by preliminary crushers (I. 346) and finally by fine grinders (I. 363), the plant selected depending on the output desired and the required fineness of the product.

Screening may be necessary in some cases to remove any very coarse or excessively fine material. A large proportion of fine material is undesirable in the sand used for furnace hearths, crucibles, muffles, retorts, and other refractory hollow-ware, but

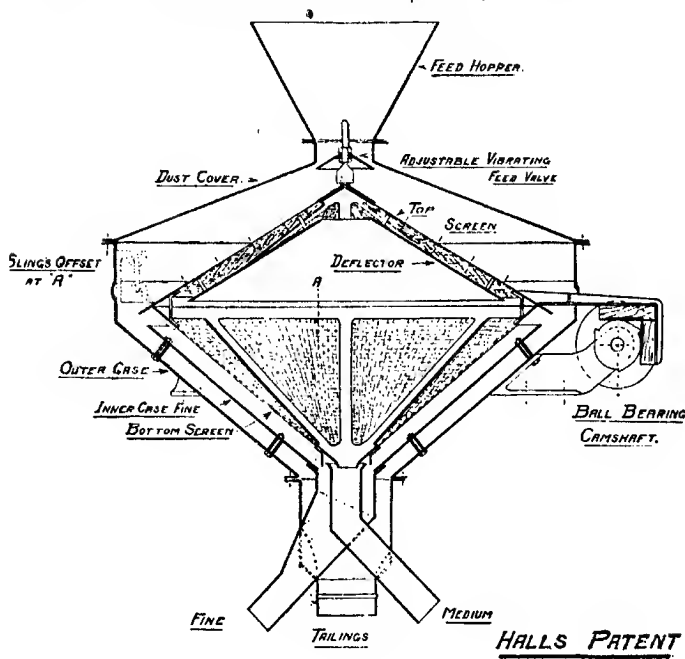


FIG. 10.—Vicona screen.

it is less serious in furnace cements, some of which are more convenient if fine. Very coarse material is undesirable for any purpose mentioned in this chapter, with the possible exception of large retorts, so that it must be screened out before the sand is used. The methods of screening are described in Vol. I. Chapter X. The Vicona screen (Fig. 10), which is described in Vol. I. p. 453, is compact and very suitable for this purpose.

Drying is unnecessary in the case of siliceous materials to be used for making refractory articles and for refractory cements, but it is most important that sands or crushed rocks used for

lining the hearths of metallurgical furnaces should be properly dried before use, for the reasons given on p. 141. The drying may be effected in any convenient manner; various methods are described in Vol. I. p. 401.

Mixing.—As sand is only one of the constituents of the various materials mentioned in this chapter, its thorough mixing with the other ingredients is a matter of great importance. In the case of materials for the manufacture of crucibles, muffles, saggers, retorts, etc., the mixing is a part of the general routine of manufacture of those articles, and is described fully in the author's *Refractory Materials: their Manufacture and Uses*.

The materials for refractory cements are best mixed in the dry state in a blending mill or in a double-shafted trough mixer, and afterwards with water in a revolving pan mill (I. 381). The customary method of mixing is very crude, and consists in placing a definite number of "shovelfuls" of the solid in the pan mill, adding as much water as it is supposed will make a suitable paste and allowing the mill to run for about 20 mins. This method of proportioning the materials is much too inaccurate; the solid materials should be weighed separately, mixed in the dry state, as just mentioned; a definite weight of the mixture should then be placed in the pan, a definite quantity of water added from a measuring tank (an ordinary domestic cistern of the "pull and let go" type is excellent), and the pan run for 20 mins. as before. By paying greater attention to the accuracy of the quantities and by first mixing in the dry state a greatly superior product is obtained.

TESTING SANDS FOR REFRACTORY PURPOSES

The principal tests to be applied to sands used for refractory purposes are the following:

1. Chemical composition (I. 237).
2. Mineralogical composition (I. 256).
3. Cleanness (I. 244).
4. Microscopical examination to determine the shape and size of the grains (I. 241).
5. A grading or sizing test to determine the proportions of particles of various sizes and to indicate whether the material is suitably graded (I. 246).
6. Refractoriness (I. 260).

In the case of rocks which are to be crushed to form sands, the following additional tests are useful:

7. The rock must be of such a texture that it can be crushed fairly readily to particles of the required size. For this reason, materials such as chert are undesirable, as the cost of grinding them is very great. The difficulty can be avoided to some extent by heating such material to redness and quenching it in cold water so as to cause great strains and cracks in the material and render

crushing easier. Unfortunately, materials so treated are not suitable for use under the most stringent conditions.

8. When the rock is heated to a temperature of 1600° - 1700° C. for four or five hours, it should not fuse or disintegrate into small pieces. If a few cracks occur or the material breaks into very large pieces, these may be disregarded, but if it disintegrates seriously, it is generally unsuitable and its use undesirable, unless it can be employed in the form of fine powder. Most rocks composed of large crystals of quartz will disintegrate under this treatment, whilst those composed of small fragments of quartz united by a siliceous cement will remain intact, and are preferable for refractory purposes.

9. On examining the rock by means of polarised light under a microscope, if the light is extinguished in waves it is undesirable to use the rock, as it has been subjected to great strains due to pressure, would crack when in use, and be very sensitive to sudden changes in temperature.

CHAPTER VIII

THE USES OF SAND IN AGRICULTURE

THE use of sand in agriculture involves considerations different from those in other industries dealt with in this volume. In metallurgy, the manufacture of refractory materials, glass, abrasives, etc., it is possible to a very large degree to choose the particular kind of sand which would be most satisfactory for the particular purpose under consideration, but in agriculture, on the contrary, the sand is largely in the soil, and its nature and amount in any particular soil can only be controlled to a small extent. In some cases, particularly in France, sand is added to a soil for agricultural and horticultural purposes, but this is only done to a comparatively small extent, as the cost of treating large areas of land in this way is prohibitive. The present chapter will deal chiefly, therefore, with the purpose of sand in soils and the part it plays in agriculture, and to some extent with the improvement of soils by the addition of sand to them.

As previously stated (I. 160), soil consists of sand and clayey matter, together with organic matter and mineral salts. The organic matter and mineral salts supply the nutriment for the plants growing in the soil, the clayey matter holds moisture which is supplied to the plant roots as it is required, whilst the sand acts as an opening material and serves the following purposes: (*a*) it renders the soil easier to dig, plough, or otherwise break up; (*b*) it renders easier the movement of growing roots in the soil; (*c*) it prevents the excessive accumulation of water, as a sandy soil holds water less easily than a wholly clay one, and thus renders drainage easier and improves the quality of the land; (*d*) it makes the soil porous and so enables a plentiful supply of air to be present; and (*e*) it acts as a support for the colloidal or gelatinous matter from which the plants primarily derive their nutriment. A good soil may, in fact, be regarded as a collection of particles of sand, each of which is surrounded by a film of colloidal matter saturated with water containing in solution various salts and other plant foods. If the colloidal film is excessively thick in proportion to the size of the grains of sand, the soil will be heavy and readily waterlogged; if the film is too thin or irregularly distributed over the grains of

sand, the soil will be light and "poor" (*i.e.* deficient in nutriment for the plants). Hence, the size of the grains of sand and the thickness of the film which covers them are two of the most important factors in the constitution of a soil.

The proportion of sand in a soil is of great importance, but it is the relative volumes of sand, colloidal matter and air, rather than their respective weights, which determine the fertility of a soil. These volumes depend in turn on the diameter and shapes of the grains of sand, for grains of numerous sizes which form a well-graded and compact mass will form a far less fertile soil than grains which are more uniform in size, as these latter are well separated and so have relatively large spaces between them. Soils are classed as light or heavy according to the relative volume of sand they contain; a light soil is one containing a relatively large volume of sand, whilst a heavy soil is one consisting chiefly of clay. Light soils are also termed *dry, warm, barley, and turnip* soils, whilst heavy soils are sometimes termed *wet, cold, wheat, or bean* soils.

The ease of working of a soil is largely dependent on the proportion of sand present. Light soils are easily ploughed or otherwise cut up, whilst heavy soils which contain less than 20 per cent of sand are difficult to work. Whilst ease of working is not important in itself, as a heavy soil merely needs a little more powerful machinery to cut it up, this quality is often an indication of the value of a soil, as will be shown later. Moreover, a soil which is difficult of penetration by a plough or spade is one in which many plants do not grow readily on account of the resistance to their roots in a heavy soil.

The shape of the particles of sand in a soil appears to be of minor importance, and no results have been published which speak in favour of grains of any particular form.

The size of the grains of sand is very important. A very coarse sand is of little value in a soil, especially if there is barely sufficient colloidal matter, as large grains tend to form large air-spaces or voids and so cannot retain sufficient moisture in the soil, but allow the water, supplied to the land by rain, etc., to percolate away very rapidly, as shown on p. 171. It is therefore very desirable that the sand should be sufficiently fine-grained, so as to present a maximum surface to the water and so exercise sufficient retentive power. The particles should not be too fine, or the interstitial spaces will be exceedingly small, as in clay soils, and the distribution of the water through them will be rendered very slow and irregular. The grains should also be sufficiently coarse to permit the air to circulate freely in the upper layers of the soil (see p. 170).

The grains should be as nearly uniform in size as possible, as this tends to ensure a maximum porosity, the size of the pores depending largely on the size and shape of the grains, whilst the total pore-space depends chiefly on the grains being of uniform size. Sands composed of grains of various sizes form compact masses, as in concrete, which are quite undesirable in soils. The latter

should be porous and, therefore, composed of uniform grains, as it has been found that the maximum fertility is obtained where the sand is fine-grained and uniform in texture. In determining the sizes of the particles of sand, care must be taken to make a proper distinction between the inert or crystalline particles of sand and the active or colloidal particles of clay and organic matter. The latter, like all colloidal material, must be composed of extremely minute particles, and a sufficient amount of this material should be present to cover all the sand particles completely without unduly filling the pores between the grains.

If the particles of soil consist of fine, yet not "dusty," grains of sand, each covered with a film of clay or other colloidal matter, and with suitable interstices or voids between the solid particles, they will produce a very valuable material, with a large surface area, ample water-retaining power, and sufficient porosity to permit proper aeration and the free movement of the particles when subjected to the pressure of plant roots.

The majority of soils of this kind are composed of sand deposited by water or wind-borne, the former being by far the more important in this country. Good examples of wind-borne soils are the black soils of the North American prairies, the Steppes of Russia, and the loess of China and elsewhere.

In this country, the importance of suitable texture of a soil is clearly shown in the Thanet sand soils of Kent. These are not rich in plant-food, but on account of their texture they are able to carry some of the best fruit and hop farms in the land, and these farms, on account of their productiveness, are very valuable. Other examples which are equally striking are the silt soils of Boston and Wisbech on the seaward side of the Fens, or the famous red soils of Dunbar. These are light and easy-working, and are not rich in plant-foods except as a result of continuous and heavy manuring, but they are of exactly the right texture for the free yet not excessive movement of water in the soil, with the result that they respond to good cultivation and carry some of the best crops in the country.

The effect of the sizes of the grains of sand in various soils is well shown in Table LI.

These soils were selected by Sir A. D. Hall, who has made the following comments on them :

"In soil No. 1 the sand is almost wholly coarse, nearly 75 per cent of the soil consisting of coarse material. Such a soil obviously could not be very productive on account of its coarseness, and could only be used for planting trees of the pine and fir class, which have roots sufficiently long to penetrate deeply into the soil, where a larger proportion of moisture occurs than at the surface. The coarseness of the sand and the presence of so small a quantity of clay accounts for the very low retentive power for water. Such soils may occasionally be used for market gardening on a small scale, but they require a considerable amount of improvement

TABLE LI.—SIZES OF PARTICLES IN TYPICAL SOILS (A. D. Hall) *

	1.	2.	3.	4.	5.	6.	7.	8.
Fine gravel	4.1	1.0	3.0	1.2	1.9	1.9	1.3	0.4
Coarse sand	70.3	49.9	33.8	5.3	3.3	6.2	21.2	0.8
Fine sand	7.0	16.1	28.0	32.1	36.8	21.4	12.5	6.4
Silt	1.5	11.1	5.6	33.3	21.0	32.5	15.0	18.6
Fine silt	5.8	5.6	10.8	5.3	14.3	13.8	11.9	13.6
Clay	4.7	9.7	6.6	11.8	13.5	17.6	28.3	42.2
Moisture	2.6	1.2	4.3	1.9	1.4	2.2	1.6	9.5
Loss on ignition . .	3.0	3.8	6.9	4.5	4.5	5.8	7.8	9.1
Calcium carbonate .	..	..	0.2	0.1	0.3	2.5	..	..

* *The Soil*, pp. 60-65.

before they can be satisfactorily employed, and they would suffer greatly from drought if they occurred in localities where there was likely to be any serious scarcity of water.

"Soil No. 1 is typical of the uplands of the Bagshot and Lower Greensand beds of the south of England. These have no supply of water near at hand, and do not readily retain rain, so that they are almost barren and only support the plants characteristic of heath lands.

"Soil No. 2 is a sandy loam from Woburn. The proportion of coarse sand is still somewhat high, so that the ground is not specially fertile, though it is very useful for market gardening, barley, and turnips, but too light to grow wheat satisfactorily.

"Soil No. 3, from the vicinity of Dunbar, is another sandy loam which does not contain quite so much coarse sand, and is therefore of greater fertility than the preceding. A soil of this kind is suitable for all crops, and especially for potatoes, for which this particular soil is highly valued.

"Soil No. 4 is a very good loam from the Thanet beds of Kent. It has a fine texture and is quite easy to work. On account of the larger proportion of fine particles, it retains water rather better than those previously mentioned, and consequently is able to withstand a drought better than those consisting of coarser sand. It is an excellent soil for general cultivation, though a little light for wheat and pasture in the south and east of England.

"Soil No. 5, from the Hastings beds of Sussex, is somewhat similar to the preceding soil, but contains a larger proportion of silt, and is consequently more retentive of water, usually being somewhat sticky and heavy, making it appear like a clay, though the proportion of this constituent is comparatively small. When suitably treated with lime, etc., they give very good results and are especially valuable as grass lands.

"In Soil No. 6 the proportion of clay is higher, whilst the proportion of sand is small, with the result that it is heavy and would be difficult to work were it not for the flints, etc., which occur in

the surface layers and keep the soil open. It is also under-drained by chalk-rock, otherwise it would tend to be very wet. Soil of this type is quite good for wheat, mangolds, beans, and pasture land, but is rather heavy for barley and turnips.

"Soil No. 7 is as heavy as can usually be cultivated and, were it not for the coarse sand present, would be too heavy to use.

"The last soil, No. 8, is practically useless for cultivation, on account of its heaviness and the expense of treatment, as nearly half the material belongs to the clay grade, and only about 8 per cent of sand is present. The soils of Oxford, Kimmeridge, and London Clay areas are of this type and are amongst the heaviest in this country."

The effect of the size and nature of the grains on the permeability of the soil is shown in Table LIII. (p. 171).

From the above comparisons of soils, the importance of the size and amount of sand in the soil will readily be realised. The best results are obtained by a mixture containing grains of sand of small and uniform size and a sufficient quantity of clay and other colloidal matter, forming a combination which retains the moisture and yet has in it sufficient sand to produce an open soil which is fairly light. Coarse sand is undesirable in most cases, but it is preferable to no sand at all.

Distribution.—The typical sandy soils of this country are either alluvial flats in the lower levels near rivers, passing into dunes where the sand accumulates near the sea, or are directly derived from some of the many coarse-grained sandy formations. The Bagshot beds and the Lower Greensand formation form wide areas in the south-east; the sandy beds of the Oolite produce similar soils in Northamptonshire and the East Midlands; farther west and northward the Bunter beds give rise to other very coarse-textured soils, as does the Millstone Grit in more elevated areas in the north. The sandy soils pass into the loams, which contain sufficient sand to be friable and to admit of percolation, yet retain sufficient water near the surface to withstand short spells of dry weather. If the sandy fractions of the loam are very fine-grained, the soil is apt to run and become sticky in wet weather, afterwards drying to hard clods. The loams are typical soils for arable cultivation and are suitable to almost all crops (see also Vol. I. p. 161).

Chemical Composition.—At one time the chemical composition of the sand in a soil was regarded as important, in that the proportion of mineral salts, etc., in the soil to a small extent depend on it; within recent years, however, it has been found that the mineralogical composition and certain physical properties of the soil are much more important than the results shown by chemical analysis.

Table LI. (p. 165) shows that the chief constituent of soil is *sand*, with a variable proportion of silt and clay. The composition of this sand is very variable, as may be judged from the following paragraphs and from the section on *Water Retention*.

The mineral portion of the soil consists chiefly of *silica*, the other constituents, which are very numerous, being in much smaller proportions. If the soil is washed to remove adherent organic matter, clay, and soluble salts, the residual "sand" will consist very largely of silica in the form of quartz, together with a variable proportion of aluminosilicates, calcium carbonate, limonite or other iron compounds, and very small proportions of other minerals. As all these mineral grains may act as supports for the colloidal matter, their composition is of minor importance and is only worth consideration when they react in such a manner as to supply some needed plant-food. For this reason, a chemical analysis of a soil gives very little indication of its value, though it may show whether it is rich or deficient in certain plant-foods. The percentage of silica in soils is so variable that it cannot be represented by any single figure.

The *alumina* in a soil is chiefly present in the form of clay, but a part of it usually exists in the sandy portion as feldspar, mica, and zeolites. These three groups of minerals all yield potash, soda, or lime when decomposed by the action of the weather, and so form a source of supply of these oxides to the soil. The function of the clay, as previously described, is to form a thin film of colloidal or plastic material around each grain of sand, this film acting as the direct storehouse of the plant-foods and of moisture in the form available for the plants to use. If too little clay is present, the soil cannot retain these foods and will be "poor," whilst an excess of clay will so fill the interstices between the grains of sand that the soil becomes impenetrable.

Iron compounds are present to a considerable extent in most soils. They are usually disseminated very finely and so are not much noticed, but in sandy soils their presence is more in evidence on account of the smaller surface area of the soil. Most iron compounds, particularly limonite (l. 189) and nontronite, do not appear either to greatly harm or benefit soils, as no relation has ever been traced between the proportion of iron oxide in the soil and its fertility, but the average proportion of iron compounds in soils is equivalent to 3.5 per cent of ferric oxide, though in extreme cases as little as 1 per cent or as much as 12 per cent may be present. Unoxidised iron salts such as glauconite and other double ferrous silicates or finely disseminated iron pyrites have a very harmful effect on the soil. Until these materials have been oxidised to ferric hydroxide, the soil remains sterile; this is particularly the case with iron pyrites, which, in the form of marcasite, easily oxidises and then yields both ferrous sulphate and sulphuric acid.

Calcium carbonate is a very important natural constituent of most soils; it is also added to make up for any deficiency of lime, as agriculturists generally agree that about $\frac{1}{2}$ -1 per cent of calcium carbonate should be present. Where it is absent from a soil, the latter becomes acid and sterile, or the plants grown on

such soil develop fungoid diseases. In strong soils containing much clay, calcium carbonate acts partly as a sand and serves to open up the soil, renders it less retentive of moisture, and enables the air to penetrate it more readily. In sandy soils it acts like clay and serves to bind the sand together and enables the soil to retain more water. Lime and calcium carbonate also serve a very important purpose in controlling the volume of colloidal gel in the soil and, therefore, its permeability and water-retaining power (p. 169), and in breaking up the rocks from which the soil is derived and liberating soluble salts. Thus the dissociation of aluminosilicates, feldspar, etc., by lime supplies potash to the soil.

Table LII., due to Schft., shows the amount of soluble salts removed from two granites by the action of water which has percolated through limestone and therefore contains carbonic acid in solution.

TABLE LII.—SOLUBLE SALTS REMOVED FROM GRANITE

	A.	B.
Potash as bicarbonate . . .	15.25	5.8 per cent
Soda as bicarbonate . . .	2.6	8.10 "
Lime as bicarbonate . . .	1.2	4.5 "
Magnesia as bicarbonate . . .	Trace	10.15 "
Silica as bicarbonate . . .	Little	Little
Iron as bicarbonate . . .	Trace	Trace

Calcium carbonate also reacts with the phosphates of aluminium and iron and liberates phosphoric acid.

The *soluble salts* in soils are chiefly mineral in origin and are largely the same as those which occur in the less pure sands. Some of these salts are very important plant-foods, but others are detrimental to plant growth. Thus, *magnesium* and *sodium sulphates* and *sodium chloride* are very harmful in soils, and where such salts are formed by the disintegration and decomposition of the rocks producing the soil, the latter is seldom very productive; if they are present to any great extent they may poison the whole of the vegetation on the land.

Soils resting upon a serpentine base are invariably very poor and sterile, on account of the magnesia which enters the soil as a result of the decomposition of the rock. Some of the Wealden clays which are rich in magnesia also give very poor agricultural results.

When calcium salts are present at the same time as the salts just mentioned, the action of the latter is diminished.

Marshes near the sea which are contaminated by salt are only able to produce certain forms of vegetation. They are of little use for agricultural purposes. It has been found that grass will grow on soils containing up to 2 per cent of salt, whilst barley

has been grown on soils containing more than $1\frac{1}{2}$ per cent of salt. Clover cannot grow on soils containing more than $\frac{1}{2}$ per cent of salt.

Potash does not occur in a useful form to any great extent in the sand portion of a soil, but is more usually associated with the amount of clay present. Its proportion increases with an increase of finely divided clayey material, which seems to point to some relation between the two. The proportion of potash varies from a mere trace in sandy soils to 1.5 per cent in some clay soils; to be useful as a plant-food, it must be in a soluble form and not present as felspar or other silicates.

Phosphoric acid is partly derived from the minerals present in the sand, such as apatite, etc., and partly from artificial manures, which are added to make up any deficiency. Usually not more than about 0.1 per cent of phosphoric acid occurs in combination with the iron oxide and alumina. The mineral phosphates are not so important as the phosphoric acid formed by the decay of organic matter and that which is added intentionally, as the mineral phosphates are less soluble and therefore less easily taken up by the plants. In general, about 0.25 per cent of total phosphorus, expressed as the pentoxide, is present, though some soils contain much more.

Organic matter in soil consists almost wholly of decomposed vegetable and animal matter, the most important constituent being that ill-defined colloidal matter commonly known as *humus*. A consideration of the nature and composition of this material is beyond the scope of the present volume, so that it is sufficient to say that the chief characteristics of this material are those of a colloidal gel, which absorbs water and swells and thereby serves as a reservoir from which plants can derive their sustenance.

Physical Properties.—The value of a soil depends far more on the possession of certain physical properties than on chemical composition, so that it is necessary to mention the more important of these properties.

The *texture* is important, as it regulates the circulation of air and water through the soil; it depends on the shape and size of the grains of which the soil is composed and on the proportion of colloidal or gelatinous matter present. If the grains of sand are too large, the soil will be coarse (p. 163); if they are too fine the soil will lack permeability (*below*); and if the grains are too irregular in shape and size, the soil will be too dense and compact. The grains of sand which constitute the bulk of the material should therefore be of medium fineness and as uniform as possible in size (p. 163).

The *permeability* of a soil depends on the interstices or voids between the grains being sufficiently large to allow air or water to pass freely through the soil. A soil with only minute voids may have a high percentage of porosity, but may not be very permeable, as the pores may be too small. This is a factor whose importance is seldom as much appreciated as it should be. For

the reason just stated, the porosity of a soil is not always a reliable guide to its value. The highest degree of porificability is possessed by soils consisting chiefly of medium-sized, sub-angular or rounded grains of sand. The film of clay or organic matter covering these grains must be as thin as the desired fertility will permit, and none of the pores should be filled with clay or organic matter. (See *Aeration and Water Retention*.)

For the relation of porosity to surface area see Table LVII.

The *aeration* of soils is very important. It is necessary that a supply of air should be able to penetrate the soil and gain access to the roots of the plant, as some of the bacteria, etc., which play an important part in supplying food to the plants are *aerobic*, i.e. they require air for their growth. Aeration is also necessary so as to produce suitable oxidising conditions in the soil, as the presence of unoxidised matter is a source of sterility and must be carefully avoided. Want of aeration also causes acidity in soils, which is a further source of lack of fertility.

The aeration of soils depends chiefly on the size of the interstices or pores between the grains, and this in turn depends on the proportion of sand present and on the shape and size of the sand-grains (p. 163).

It should be remembered that a high porosity does not necessarily provide good aeration (p. 169). In Table LVII. (p. 174) it will be seen that clay soils have a high porosity, but the aeration and permeability are low because the particles are extremely small and the interstitial spaces are consequently very minute, with the result that air only passes through them with great difficulty, owing to the high resistance to flow imposed by small channels. Soils containing much moderately fine sand, however, consist of larger particles, and whilst the total pore-space is not so large, the air-passages are larger and offer less resistance, so that the soil with the smaller porosity has, in this case, the greater permeability and capacity for aeration. It is important to observe that in two sandy soils having the same total porosity, the one with the largest-sized pores would, of course, be the more easily aerated. It should also be observed that in many clay soils the large pore-space is largely filled with water, so that the passage of air is impossible. Sandy soils, being less retentive of water, usually have a greater capacity for circulating air.

Water Retention.—It is, of course, important in agriculture that a soil should contain sufficient water to supply the roots of the plants growing on the land with as much as they require. A clay soil containing a large proportion of colloidal matter will absorb a considerable amount of the rain which falls on the land, as one of the characteristic properties of clay and other colloids is their power of swelling when wetted, so that they form a reservoir of water in the soil. The swelling also decreases the amount of pore-space in the soil, and thus renders the passage of water through the soil very difficult and slow. Not only is its flow diminished

by the increase of friction in the narrow channels thus formed between the particles, but, in the case of clay, the dimensions of the particles are so small that most of the contained water does not flow at all, but merely diffuses through the soil. Moreover, water cannot flow through a bed of clay or loam unless the particles have first been allowed to expand and take up a sufficient volume of water. Hence, clay is impervious to water and will not allow it to pass through into the subsoil very readily, but tends to retain it and so keeps the surface of the soil moist. If too much clay is present, an excess of water will be retained and the land may become water-logged; this is just as harmful to some plants as the absence or scarcity of water is to others, so that an excessively clayey soil is undesirable. Sand, on the other hand, has no absorptive power, so that very little water is retained by it; most of the water rapidly percolates through into the subsoil and escapes without benefiting the plants growing on the surface. A "soil" composed wholly of sand would, therefore, be sterile. To be of value, a soil must consist of clay and sand of such a nature and in such proportions as to retain the desired amount of water without allowing it either to percolate away too rapidly or to be retained too long.

The amount of water passing through soils containing sand and clay in different proportions is well shown by some experiments made by King,¹ who maintained water at a head of 2 in. above columns 14 in. long and 1 sq. ft. in section of various sands and clays, and measured the number of inches of water passing through each column in 24 hours. His results are shown in Table LIII.

TABLE LIII.—PERMEABILITY OF SANDS TO WATER

Material	Size of Particles.	Inches of Water per sq. ft. passing in 24 hours.
Sand	40- 60-mesh	301.0
Sand	60- 80 "	160.0
Sand	80-100 "	73.2
Sand	160-mesh and finer	39.7
Clay loam . . . . .	..	1.6
Black marsh soil . . . . .	..	0.7

It will be noticed that with the finer particles there is a great diminution in the rate of flow. Comparing the various sands it will be seen that the one passing through a 100-mesh sieve will retain nearly 8 times as much water as one which passes through sieves of between 40- and 60-mesh. When clay is introduced the percolation is enormously reduced, the amount of water passing through a marshy soil being very small indeed. Hence, when a soil is rich in mineral salts, bases, etc., it may be quite useless if the texture of the soil is such as to prevent the proper distribution of moisture.

¹ *Physics of Agriculture*, Madison, Wis., 1901.

Another experiment which possibly corresponds more closely with the drainage of soils *in situ* than the preceding one, consists in measuring the amount of water drained from various sands and soils in a certain time. The results of several such tests are shown in Table LIV. and demonstrate clearly the effect of sand on the water-retaining power of the soils :

TABLE LIV.—WATER DRAINED FROM SANDS AND SOILS *

Material.	Inches of Water lost in				
	30 Min.	31-60 Min.	24 Hours.	2 to 11 Days.	12 to 21 Days.
No. 20 sand . .	10.25	4.68	..	..	..
No. 60 sand . .	5.67	4.52	..	..	..
No. 100 sand . .	1.21	.84	..	..	..
Sandy loam . .	..	..	2.64	5.07	.9
Clay loam . .	..	..	1.96	2.11	.49

* Hall, *The Soil*, p. 82.

If columns of sand and clay mixed in various proportions are saturated with water and then allowed to drain, the quick drainage of the upper layers of sand is very evident, whilst columns of clay maintain a fairly uniform proportion of water throughout their height. It will thus be seen that the effect of sand in a soil is to increase the aeration and to allow water to percolate through much more rapidly than if much clay were present in the soil. Sand also increases the rate of evaporation of moisture from the surface of the soil.

Whilst sand is advantageous in making a soil light and so preventing the accumulation of water, it is disadvantageous inasmuch as sandy soils are much less capable of withstanding drought than those containing a greater proportion of clay, because the clay particles act as reservoirs or sponges, whereas sand itself has no absorbing power (p. 171).

In a drought, the gravels and coarse sands always suffer first ; this is not merely because they start with less water, but because in a sandy soil there is a very limited movement of the subsoil water to the roots of the plant. Should a drought continue, the clay soils begin to suffer next, because the water is moved so slowly through the very fine pore-spaces that the supply cannot keep pace with the loss by transpiration and evaporation. The soils which are least affected by drought are the deep, loamy sands of very uniform texture, which are fine-grained enough to possess a considerable surface, and yet not so fine as to interfere with the free movement of water in the soil.

Apparent Density.—The weight per cubic foot or apparent density of a soil is very closely related to its porosity and power

of water retention; it is dependent on the proportion of sand, clay, etc., present and on the sizes of the particles.

The true density or specific gravity of various constituents of soils, together with their apparent density, which takes into account the voids between the particles, are shown in Table LV.

TABLE LV.—TRUE AND APPARENT DENSITY OF SOIL CONSTITUENTS

	True Density.	Apparent Density when Dry.
Humus	1.20	0.34
Clay	2.50	1.00
Sand	2.60	1.45
Calcium carbonate	2.75	1.90
Hydrated iron oxide	3.4 to 4.0	3.00

When mixed in various proportions the substances just mentioned yield soils of varying apparent density, some of which are shown in Table LVI., due to Hall¹:

TABLE LVI.—APPARENT DENSITY OF SOILS

	Apparent Density.	Weight per cu. ft.
Heavy clay	1.062	66.4
Sandy clay	1.279	79.9
Sandy clay subsoil	1.180	73.7
Light loam	1.222	76.4
Light loam subsoil	1.144	71.5
Sandy loam	1.225	76.7
Sandy peat	0.782	48.9
Light sand	1.266	79.2
Washed sand	1.450	90.6

It will be seen that clay soils usually described as "heavy" are really less dense and weigh less per cubic foot than some of the lighter soils, and that pure sands are the densest of all. The farmer's terms of "light" and "heavy" land refer to the ease with which any particular soil can be ploughed or otherwise worked, and not to the weight of the soil moved; sands which he calls "light" being, as Table LVI. shows, heavier per cubic foot than the clays which the farmer calls "heavy" soils.

The reason clayey soils have a lower apparent density is that they have a greater pore-space than sands, as shown in Table LVII. compiled by King:

¹ *The Soil*, p. 69.

TABLE LVII.—POROSITY AND SURFACE AREA OF SOILS

	Porosity, per cent.	Area of Surface in sq. ft. per cu. ft. of Soil.
Finest clay	52.9	173,700
Fine clay soil	48.0	110,500
Loamy clay soil	49.2	70,500
Loam	44.1	46,500
Sandy loam	38.8	36,900
Sandy soil	32.5	11,000

In the finer-grained soils, the weight of the small particles of clay is not sufficient to overcome the friction which prevents the particles from arranging themselves so as to have the minimum pore-space, and consequently there is in such soils a larger proportion of interstices.

The Addition of Sand to Soils.—In cases where a soil is very heavy, but otherwise valuable, it is sometimes profitable to add a sufficient quantity of sand to the upper layers to produce a more open texture, and so render the soil more fertile. Whether this practice will be profitable depends on the nearness of a supply of suitable sand and the cost of applying it to the land. Where such an addition of sand is to be made, a material having properties described on p. 163 should be employed. Silver sand has been used very satisfactorily in the south of England for the treatment of some clayey soils. A similar yet smaller effect is obtained by mixing a sandy soil with another heavier soil; this treatment is termed *warping* or *dry warping*. The sandy soil acts in the same manner as sand, but a much larger quantity is required. It is a curious fact that, whilst the addition of sandy soil to a clayey soil is practised to some extent, it is by no means so usual as the addition of clay to a sandy land, though the latter is far less remunerative.

The chief difficulties experienced by adding sand or a sandy clay to another soil are that such an addition does not increase the amount of plant-food in the soil, so that the relative amount of organic matter in the treated soil is less than that in the original material, and heavy fertilising is also necessary unless the original soil is exceptionally rich in plant-food.

The Use of Non-siliceous Sands in Agriculture.—Various sands which are not necessarily of a siliceous character are used for dressing land, especially for increasing the plant-foods in the soil. Thus, calcium carbonate is sometimes added in the form of shore sands containing a large proportion of minute fragments of shells. This treatment has been found to be very satisfactory where the shell sand is readily available and labour is cheap. The "manure gravels" which occur beneath the Boulder Clay in the southern parts of Wexford (l. 76) consist largely of shell sands and gravels,

and are used for dressing agricultural land. In America, phosphate sands are used to a large extent as a means of adding plant-food to soils.

Preparation of Sands for Use in Agriculture.—It is not profitable to prepare siliceous sands prior to adding them to a soil, on account of the high cost and the large amount of material required, but sands which form one ingredient of fertilisers may, however, be prepared to some extent by grinding, washing, and drying them before use. For instance, the phosphate sands found in the United States contain a large proportion of clay which is removed by washing and recovering the sand in settling cones (I. 395). The *drying* is effected by the settling cone, some form of artificial dryer being used if necessary. The *grinding* of phosphatic sands is usually effected in a ball, tube, or roll mill prior to their conversion into super-phosphate.

Other crushed rocks such as phosphate rock, coprolites, etc., are also used for dressing soils, but they are scarcely within the compass of this volume.

Testing Sands for Use in Agriculture.—Where sands are to be added to the soils, the following tests may be applied in order to ascertain whether they are suitable for the purpose :

1. Chemical composition (I. 237). This applies specially to fertiliser sands, which should contain an ample proportion of plant-food. In siliceous dressings the chemical composition is not so important.

2. A sizing or grading test (I. 246), in order to ascertain the texture and the size and grading of the particles.

3. An elutriation test (I. 252) to ascertain the proportion of clay present.

4. A microscopical examination (I. 241) to ascertain the shape and nature of the particles.

5. A determination of the apparent density (I. 259).

6. A permeability test (I. 263) and, if desired, a porosity test (I. 261), though the latter is of less value in agriculture than is commonly supposed (p. 169).

CHAPTER IX

THE USE OF SANDS FOR FILTRATION

THE purification of river, lake, and other waters for domestic use is effected in various ways, depending on the impurities to be removed. The chief impurities may be classed as follows: (a) suspended dirt, organic matter, etc., (b) bacteria and other disease-producing organisms, etc., which are also in suspension, and (c) mineral salts and other substances in solution.

Substances in solution are often removed by precipitation, which puts them into suspension; they are then removed like other suspended matter, by sedimentation or filtration, usually through a sand filter, which is especially useful for treating water on a large scale, such as that required for use in towns and large industrial centres. In addition to the filtration of water, sand filters may be used for filtering oils, acids, etc.

Sand filters are of two types, known respectively as (a) slow-sand filters, and (b) rapid-sand filters, the latter being rather coarser than the former, so that the water passes through them more rapidly, pressure or suction being sometimes used to increase the rate of flow still further.

The relative value of each type of filter is shown below:

Slow-sand filters are preferable where the water is contaminated by sewage, but is fairly free from other suspended matter. If coarse suspended matter is present, sedimentation followed by slow-sand filtration is very satisfactory. Water which has an objectionable odour is also best treated by the slow-sand method. The principal disadvantages of the use of slow-sand filters are that the process occupies a very large area and is extremely slow, whilst at the same time frequent cleansing is necessary to ensure proper action.

Rapid-sand filters are useful where the sewage contamination, if present, is not great, and also where the water is coloured. When fine suspended matter is present, sedimentation followed by rapid-sand filtration is usually the best method.

The value of a sand filter for water is due to two factors, (a) the straining action of the sand in holding back coarse matter, and (b) the formation on its upper surface of a layer of slimy material

composed of clay, vegetable matter, such as algae, etc., which forms a support for the growth of organisms and so arrests a large proportion of any bacteria which occur in the water. After some time, a bacterial jelly also coats the particles to a considerable depth and stops any bacteria passing through the filter. Some of the bacteria also oxidise organic matter, etc., and effect other important changes.

A sand filter, if sufficiently large and used for a sufficiently long time, will completely clear a turbid solution of all suspended matter. The latter is chiefly retained in the top half-inch of the filter, the matter so collected arresting the passage of all other suspended matter. If the suspended matter is extremely fine, the action of the filter is greatly increased by the addition of a precipitant or coagulator, which forms a voluminous precipitate which surrounds the fine particles.

When a sand filter has been in operation for some time, its output is reduced as a result of the accumulation of material on the surface and the growth of bacterial and other matter through the filter bed, so that it must be cleaned periodically and a new surface of sand exposed. The latter is soon coated over with the slimy layer, and the filter then resumes its normal activity. The cleaning is usually effected by removing $\frac{1}{2}$ -1 in. of sand at suitable intervals. In some cases it is necessary to scrape off a thin layer every few days, whilst in others once every 4-6 weeks is sufficient. The filters used for the London water supply are scraped every 30-40 days. When a foot of sand has been removed in this way, the filter must be re-sanded and the sand in it brought to the original level. In most cases, the sand scraped from the filters may be washed and used over again.

Sand filters consist of layers of material of various sizes, the finest being at the top and the coarsest at the bottom; in many of them the lower part is occupied by gravel, stone, shingle, etc., from $\frac{1}{2}$ -2 in. diameter, in which are laid open-jointed pipes, 4-8 in. diameter, to facilitate the removal of the filtered water.

A typical foundation consists of :

6 in. broken stone or shingle	. . .	1-2 in. diameter.
3 in. gravel	. . . . .	$\frac{1}{2}$ -1 in. "
6 in. gravel	. . . . .	$\frac{1}{4}$ - $\frac{1}{2}$ in. "

In rapid-sand filters the foundation is sometimes only about 8 in. deep.

The depth of the sand layer should not be less than 1 ft. and should preferably be 2-3 ft. deep. In England 2 $\frac{1}{2}$ -3 ft. is the average depth of the sand bed, both for slow- and rapid-sand filtration. The sand bed must be sufficiently thick, so that its efficiency will be maintained after about 1 ft. of material has been removed by the cleaning process.

The effective working of a sand filter depends very largely on the depth or "head" of water above the sand bed. If the head is too little the filtration will be slow, whilst if too great, the water

will burst a passage through the sand and pass through without being filtered. The head should in no case exceed the depth of the sand bed, and should preferably be about half the depth, 18 in. being a good average, though in some cases a head of only 9 in. is employed.

The average rate of filtration by the slow-sand method should be 2-3 million gallons per acre per day. According to Koeh, the speed of the water passing through the filter should not be greater than 100 mm. or 4 in. per hour. This corresponds to nearly $2\frac{1}{4}$ million gallons per acre per day.

The sand used for filtration purposes should have certain properties which may be classified under the following heads: (a) chemical composition, (b) shape of grains, (c) size and grading of grains.

Chemical Composition.—The sand used for filtration is usually of a highly siliceous nature, and should be reasonably pure. The sand in large filters generally consists of quartzose grains, but for small domestic filters kieselguhr is sometimes used and is an excellent filtering medium.

Clay, silt, etc., should not be present, and, if necessary, should be removed by washing, as such substances fill up the interstices between the larger grains and decrease the permeability of the filter and the rate of filtration.

Pennink has suggested that the sand need not be quite clean, as a small proportion of very fine particles aids in retaining bacteria, etc., but most authorities state that the sand should be as clean as possible.

Lime compounds, especially *chalk*, are undesirable, as they harden the water passing through the filter. A very small proportion is not serious, as it will soon be removed by solution in the percolating water.

Iron compounds in the form of limonite (I. 189), which exists as a surface coating on the sand grains, is sometimes advantageous, especially if the limonite is in the state of a colloidal gel, as it then increases the absorptive power of the sand for organic substances, and sometimes it also increases the rate of oxidation. Colloidal ferric hydroxide, when present, is electro-positive and combines in some way with the electro-negative bacterial jelly formed on the surfaces of the sand grains in old filters. A large amount of iron compounds is, however, undesirable, as it then tends to clog the filters and may also impart a yellowish or brown colour to the water passing through them.

The Shape of the Grains.—Many people who use sand for filtration purposes appear to consider that the shape of the particles of sand is of no importance. Sharp angular sand or crushed quartz is generally preferred, but it is often stated that there is little difference, as the grains soon become coated with jelly. It is also claimed that rough-surfaced grains are preferable, as the bacterial growths adhere more readily to them than to smooth-faced grains.

Rounded grains, however, have several advantages, as a sand

composed wholly of rounded grains has a greater proportion of voids and, therefore, a greater rate of filtration than a sand consisting wholly of sharp angular grains. In addition to this, rounded grains can never interlock and thus reduce the permeability of any part of the filter bed, whereas angular grains interlock readily. Notwithstanding these apparent advantages, it is found in practice that apart from excessively angular, laminated, and flaky grains, the shape is of minor importance, though rounded grains, when obtainable, are to be preferred.

The Size of the Grains.—The grading of a sand for use in filtration is of great importance, as the rate of filtration, the effectiveness of the purification, and the uniformity of flow through the filter depend upon it.

In considering the sizes of the sand grains it is necessary to take into account (a) the nature of the liquid to be filtered, and (b) the amount of purification required. A coarse sand will give rapid filtration but poor purification, whilst a very fine sand will give a good purification but will filter very slowly. A compromise between these two extremes must usually be decided upon, the filtering medium being as fine as possible consistent with proper drainage and the aeration of the interstices.

Particles small enough to be regarded as silt (1. 1) or "dust" are undesirable, as they fill the pores and prevent aeration, which is necessary, in the case of a public water supply, for the proper oxidation of any organic matter in the water. Consequently all particles less than 0.003 in. diameter should be removed from the sand by washing.

In filtration any consideration of the size of the sand should be based upon two factors, viz. (a) the effective size, and (b) the uniformity coefficient.

The *effective size* has been defined by various engineers in different ways. One of the most convenient is to define the maximum and minimum sizes of grains which enable the filter to work at a given rate. The effective size is defined as the smallest size of grain contained in 90 per cent of the material, or as the size of grain than which 90 per cent of the material is coarser.

The *uniformity coefficient* is found by dividing the largest size of the smallest grains which constitute exactly 60 per cent of the material by the smallest size of grain in the coarsest material, which represents exactly 90 per cent of the material.

Another definition of the uniformity coefficient is as a figure which, "when multiplied by the effective size, will give a size of grain of which 60 per cent of the material is finer." Thus, suppose a sand has 90 per cent of grains coarser than 0.016 in. diameter and 60 per cent finer than 0.024 in. diameter, the effective size is 0.016 in. and the uniformity coefficient is 1.5 (1.5 times 0.016 in. = 0.024 in.).

The uniformity coefficient is not very satisfactory, yet it is difficult to replace it by any other figure based on more scientific considerations. It should usually be about 1.5-1.7.

The objections to such definitions are that they are on an empirical or arbitrary basis, and that they overlook the fact that the 10 per cent of fine material is equally as important in the process of filtration as the 90 per cent of the coarser matter. The size of the smallest particles of sand should clearly be a trifle less than that of the smallest particles to be removed by filtration, as if the sand is larger some of the particles of suspended matter may pass through the filter. In practice, however, this leads to the use of unnecessarily small particles, because it disregards the effect of the bacterial jelly which forms on the surface and, to some extent, in the interior of the filter. As a matter of experience it is usually found that the most efficient filtration is effected if 90 per cent of the grains of sand are larger than 0.010 in. diameter, with few of the grains larger than 0.015 in. and none exceeding 0.01 in. diameter. This corresponds to an "effective size" of 0.010 in.

The figures in Table LVIII. are given by several filtration plants :

TABLE LVIII.—SIZE OF GRAINS FOR FILTRATION

	Effective Size, In.	Uniformity Coefficient.
Mechanical filter, Minneapolis, Min., U.S.A.*	0.014-0.018	1.65
Filtration and softening plant, Columbus, Ohio, U.S.A.†	0.016	1.5
Metropolitan, London ‡	0.015	..
Antwerp‡	0.016	..

* *Engineering Record*, Nov. 18, 1911.

† *Engineering Record*, Feb. 24, 1906.

‡ *Modern Methods of Water Purification*, Don and Chisholm.

The effective size of the sands used at Berlin, Hamburg, and Altona, in Germany, is slightly less than for the Metropolitan Board, London.¹

In an ideal sand for filtration, all the grains would be of the same size and approximately 0.008 in. diameter, so that the uniformity of a sand would best be represented by the proportion of grains exactly this size. As no natural sand is wholly uniform it is necessary to allow a reasonable variation from any given diameter, and when this is done, the uniformity of a sand may be represented by the percentage of grains between 0.05 and 0.010 in. diameter. Thus, if a sand contained 87 per cent of grains between 0.015 and 0.025 in. diameter, its uniformity would be expressed as "87 per cent." This method of expressing the uniformity with reference to a given size of particle is more of service for filtration purposes than a more general expression; where the latter is preferred the uniformity may be expressed in a similar manner

¹ *Modern Methods of Water Purification*, Don and Chisholm.

by ascertaining the average diameter of the grains and then ascertaining the proportion of grains within definite limits greater or less than the mean.

The uniformity or otherwise of a sand can be most easily appreciated by plotting each size and percentage on a graph, such as that recommended by Boswell (I. 215). A wholly uniform sand will be represented on such a graph by a vertical straight line, and even when a sand is not wholly uniform it is easy to see the extent of its uniformity.

The rate of percolation depends on the size of the particles and is inversely proportional to the area of the grains per unit-volume. Thus, Don and Chisholm found that under a head of one hundredth of the thickness of the filter bed, water passed through a clean bed three times as fast with a sand whose effective size was 0.014 in. as with one whose effective size was 0.008 in. The rate of percolation through the London sand (p. 180) is just under 4 in. per hour.

When a bacterial jelly has formed on the sand grains, the effectiveness of purification depends on the surface of such jelly; if the latter is uniformly distributed the efficiency of the purification will depend on the surface area of the grains of sand. As the jelly is largely colloidal in character and only affects the purification of the water which comes into intimate contact with it, the best separation will obviously be obtained by splitting the liquid into the thinnest possible layers, so that the bacterial jelly on the grains of sand can come into the closest possible contact with the deleterious matter, and all organic matter can be oxidised. According to Baldwin and Wiseman, a sand having an average diameter of 0.014 in. will divide the water into layers about 0.002 in. thick, whilst sands 0.25 in. diameter will only divide it into layers about 0.01 in. thick, so that the separation will be far less effective. The surface area can be calculated from the results of a grading or sizing test as described in Vol. I. p. 211.

According to Don and Chisholm, sand consisting of grains 0.04 in. diameter has an area of about 500 sq. ft. per cu. ft., and one consisting of grains 0.005 in. diameter (=100-mesh) has a surface area of about 5000 sq. ft. per cu. ft. A fine clay with grains less than 0.004 in. diameter has a surface area of at least 400,000 sq. ft. per cu. ft.

From the foregoing it will be realised that the best sand for filtration purposes is one composed almost wholly of rounded particles 90 per cent of which are between 0.004 in. and 0.01 in. diameter. It is not always possible to use so uniform a sand, but an endeavour should be made, by suitable methods of preparation, to remove those grains which are outside the limits just mentioned, or otherwise a sand with a lower power of filtration will be employed.

Sources of Sand for Filters.—Various shore, dune, river, and pit sands are used for filtration purposes; dune sands are generally preferable to river sands, as the latter usually vary considerably

in texture, whilst the former are generally fine and uniform. The coarser sands of Leighton Buzzard (I. 119) are largely used for filtering water, and the Appin quartzites near Kentallen, Argyllshire, are used for filtering acids. Sources of kieselguhr for house filters are described in Vol. I. p. 96. A white sand is usually preferred to a coloured one, and a local sand, when obtainable, is generally used on account of its lower cost.

Preparation of Sands for Filters.—In most cases practically no preparation is considered necessary; the sand may, if necessary, be *washed* to remove dirt, silt, etc., by one of the methods described in Vol. I. p. 384, and *screened* (I. 441-468) to remove excessively coarse or fine particles, so as to produce as uniform a sand as possible. The efficiency of a properly prepared sand is much greater than that of any crude sand, yet many water-works engineers fail to perceive this and employ an unprepared sand because of its low first cost.

Where a rock such as quartzite is the source of the sand, this must be crushed and ground (I. 346) to the required size, and, if necessary, screened as above.

Sands which have been in use for some time as filters need to be washed before they can be re-used.

Testing Sands for Filters.—The principal tests of sand for filters are:

1. A cleanness test (I. 244).
2. A size or grading test (I. 246) to ascertain whether the sand grains are within the suggested limits.
3. A microscopical examination (I. 241) to determine the shape and nature of the grains.
4. A chemical analysis (I. 237) to show the composition of the sand.

CHAPTER X

THE USES OF SAND IN THE CHEMICAL INDUSTRY

The principal substances in the manufacture of which sand is required are :

1. Silicon and silicon compounds.
2. Ferro-silicon and other ferro alloys.
3. Sodium silicate.
4. Ultramarine.
5. Zeolites, including permutite.
6. Carborundum and other carbides.
7. Glass (see Chapter XII.).
8. Fused quartz (see Chapter XII.).

Silicon and silicon compounds may be produced from silica. A very crude form of the metal silicon was prepared by Berzelius in 1808 by fusing a mixture of iron, carbon, and silica, but, according to Vigoureux, the best method consists in heating a mixture of 20 parts of powdered silica and 16 parts of magnesium, together with 9 parts of calcined magnesia to slow down the reaction. The temperature to which the material is heated should be 300° - 400° C. at first and then up to red heat. By this treatment the silica is reduced and the magnesium forms magnesium oxide, which may be removed with hydrochloric acid; the crude silica is further pyrrified, if necessary, by repeated heating with hydrofluoric and sulphuric acids.

Where a crude silicon will suffice, as when it is to be used for preparing silicon compounds, it may be made by heating white sand with one-quarter of its weight of magnesium powder. The reaction is very vigorous, and is accompanied by a flash of light.

A method of preparing silicon on a large scale consists in heating silica and carbon in an electric furnace, either with or without a flux. The carbon removes the oxygen from the silica, the carbon dioxide being evolved as a gas, leaving the silicon behind.

Graphitoidal silicon may be produced by heating magnesium and fine sand, fusing the product with aluminium and cryolite, and then treating it with water and acids. This leaves glistening black particles of graphitoidal silicon.

Silicon nitride may be made by heating a mixture of sand and carbon to a temperature of 1400° - 1500° C. in a current of nitrogen. The sand is reduced to silicon by the carbon, and at high temperatures, combined with nitrogen, forming silicon nitride, which corresponds to the formulae SiN , SiN_2 , and Si_3N_4 respectively.

Silicon Alloys.—In order to impart a greater hardness and a greater resistance to acids, and also to act as a deoxidant in the manufacture of steel and some other metals, various silicon alloys are employed. One of the best-known of these, *ferro-silicon*, is made by heating sand with carbon and iron or iron turnings in a blast furnace or electric furnace. By this treatment the sand is reduced to silicon, which combines with the iron, giving a product containing from 8-95 per cent of silicon, according to the purpose for which it is to be used. The higher grade alloys containing the larger proportions of silicon are always made in electric furnaces. Other silicon alloys which are made in a similar manner include *ferro-silicon-aluminium*, which contains 12-15 per cent aluminium, *ferro-silico-manganese* which contains 50-70 per cent of manganese, *ferro-silico-manganese-aluminium*, which contains 9-22 per cent of manganese and 4-5-12 per cent aluminium, and *ferro-silico-manganese-calcium-aluminium*, which contains 50-55 per cent of manganese, 18-22 per cent of calcium, and 4-5 per cent of aluminium.

Sodium Silicate.—A somewhat indefinite compound of soda and silica commonly known as *water-glass* may be made by boiling under pressure a mixture of sodium carbonate, sodium hydroxide, and silica. The process is carried out in an iron boiler, under a steam-pressure of about 60 lb. per sq. in., and is continued for about 12 hours until a syrupy liquid containing about 50 per cent of sodium silicate is produced.

Sodium silicate may also be made by fusing a mixture of silica and a sodium salt, such as the carbonate, hydrate, or sulphate, together with a little charcoal, in a reverberatory furnace. The treatment is continued for about 8 hours, and when the reaction is complete, the product is cast into moulds. When cold, the blocks are crushed and dissolved in water or sold as *rock silicate*.

A mixed silicate of soda and potash is produced by the simultaneous use of both alkalies in the process of manufacture.

Ultramarine.—Various green and blue pigments of indefinite composition, known as ultramarines, are made by heating a mixture of china clay, sodium carbonate or sodium sulphate, carbon, silica, and sulphur in approximately the following proportions: china clay 100 parts, sodium carbonate 103 parts, carbon 4 parts, fine sand 16 parts, sulphur 117 parts.

Smalt is made by fusing a mixture of fine sand, potash, and oxide of cobalt in proportions to produce the various shades required.

Zeolites are complex aluminosilicates of low stability. They are sometimes made by fusing crushed quartz or sand with a flux. T. D. Riedel in 1906 patented the use of a mixture of 3 parts of kaolin, 6 parts of quartz or sand, and 12 parts of sodium carbonate,

which are mixed and fused until the zeolite is formed. *Permutite*, which is a zeolite used for water softening, may be made by fusing sodium carbonate, china clay, or alumina and fine sand. The product corresponds in composition to the formula $\text{Na}_2\text{Al}_2\text{SiO}_5 \cdot 6\text{H}_2\text{O}$. *Manganese permutite* is made of sand, alumina, and a higher oxide of manganese, whilst in *calcium permutite* the sodium is replaced by calcium. When used for water softening, the sodium or other metal of the permutite replaces the metal which causes the hardness in the water, thus softening the latter. Different kinds of permutite are used for removing different hardening materials from water.

Carborundum and other carbides and carboxides are made from mixtures of silica, coke, sawdust, and salt in various proportions, and treated in slightly different ways in an electric furnace. Their nature and manufacture have already been described (I. 86).

Sources of Sand.—When sand is used as a chemical reagent it is solely as a convenient means of obtaining silica in a relatively pure and finely divided form, though the physical properties are often important on account of their influence on the rate at which the desired reactions proceed.

The principal siliceous materials available for preparing chemical compounds are as follows:

Powdered quartz or fine sand is largely used where the ingredients of the mixture are to be fused, as, provided the material is ground sufficiently fine, the fact that it is crystalline is not of great importance. The reaction does not, of course, take place so rapidly as would be the case if an amorphous form of silica were to be used, but by raising the temperature to which the mixtures are heated and prolonging the heating, the reaction takes place sufficiently rapidly to make the use of this material successful on a commercial scale, whilst the sand is much cheaper than amorphous silica. Sand or powdered quartz is used in the manufacture of silicon, ferro-silicon, and other silicon compounds, zeolites, carborundum and other carbides, and sometimes in the manufacture of sodium silicate and ultramarine. An impure form of silica, viz., a siliceous iron ore, is sometimes used in the manufacture of ferro-silicon. Where the reaction does not take place sufficiently rapidly with crystalline silica, an amorphous form of silica may be used with advantage.

Crushed silica rocks may be employed for the same purposes, but the fact that sand does not need crushing is in its favour.

Flint which has been calcined at red heat, quenched in water, and ground to a very fine powder, is often used as a source of silica for making sodium silicate, as flint is a natural form of amorphous silica, and therefore is more readily attacked and dissolved than the crystalline forms. Flint may also be used for making other chemical compounds, though the cost of grinding it is usually greater than the cost of producing the additional heat needed when fine sand is used.

Kieselguhr, is one of the most satisfactory materials for taking

part in a chemical reaction, on account of its skeleton texture (I. 96), which renders it more easily attacked than any other form of silica. It is sometimes used, instead of powdered quartz or flint, for making sodium silicate, and it is generally used as a source of silica in ultramarine manufacture. Its use has not been developed to any great extent in other chemical industries, except as an absorbent for chemicals, especially acids, to facilitate their transport. Thus, if an acid is absorbed in kieselguhr, there is no fear of it being spoilt in transport.

For this purpose, the kieselguhr should be clean, pure, and as highly absorbent as possible. The other properties desired are practically the same as when kieselguhr is used as an absorbent for nitroglycerine in the explosive industry (see Chapter XIV.).

Glauconite sands have been suggested as sources of potash and other chemical compounds. Thus, H. W. Charlton¹ has proposed to recover potash from greensand by digesting the latter in a finely divided state with lime and water under a pressure of 225 lb. per sq. in. maintained for 2-4 hours. The liquid is then filtered, the potash being afterwards recovered from the solution in a very pure state. According to Charlton, one ton of greensand will yield 100 lb. of potash.

E. Hart has been granted several American patents for the treatment of greensand with strong acids to remove the metallic oxides and to convert the potash into chlorides or sulphates, which then enter into solution. The insoluble matter is removed by filtration and the potash recovered from the solution by evaporation and crystallisation.

M. Hauber² has patented the process of mixing greensand with ferrous sulphate and then heating it to a dull-red heat to decompose the sulphate and form combined sulphates of potassium and aluminium, which are dissolved, separated from insoluble matter, and the soluble salts recovered by evaporation and crystallisation.

Many methods for the recovery of potash from glauconite and other sands have been tried; they can only be profitable when such important sources of potash as the Stassfurt beds are either exhausted or rendered unavailable by war or similar extraordinary causes.

Desirable Properties.—The physical nature of the silica, used in the preparation of chemical compounds is of minor importance, provided the particles are sufficiently small so that they can react rapidly with the other substances and produce the required compound as quickly as possible. It will, therefore, be obvious that the siliceous materials which can be employed are limited to fine-grained sands and to those which can be ground at a remunerative rate.

The shape of the grains is of no importance whatever, but it is most important that they should be extremely small. As has

¹ *J. Ind. Eng. Chem.*, 1918, 10, 6.

² U.S. Pat. 1,323,764 (1919).

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been shown previously (p. 142), fine particles of silica are much more readily attacked by other substances either in the liquid or solid form under the influence of heat than are larger particles. The maximum speed of reaction will therefore be obtained by the use of finely divided materials.

Amorphous materials are preferable to crystalline, as the individual particles are much smaller and much more easily attacked by other chemical substances. Hence great fineness is one of the essential properties of siliceous material used in the production of chemical compounds. Extreme fineness can only be obtained by prolonged grinding or by precipitating the silica from solution; *e.g.* by adding acid to a solution of sodium silicate and collecting the precipitated silica. For most purposes such extremely small particles are not necessary, and it will usually suffice if a sand is used in which no particles are larger than 0.02 in. in diameter.

The chemical composition of the sand may or may not be important. Where a chemical compound of great purity is to be produced it may be desirable to use as pure a form of sand as possible, or the product may require an excessive amount of purification before it can be used. Where a less pure product is required, a little impurity in the sand is not serious, though pure raw materials should be employed as far as possible. Fortunately there are in this country abundant supplies of sand containing 98 per cent or more of silica, and these are quite pure enough for most chemical purposes. When a chemical manufacturer complains that such a sand is not pure enough for his work, it will usually be found that he is really referring to the unsuitable physical nature (such as the size of the particles) rather than to the chemical composition of the material. In some cases, however, the sands used must be almost completely free from iron compounds, and the sand used in making carborundum and ferro-silicon should also be as free as possible from alumina.

Preparation of Sands for use in the Production of Chemicals.—

As a general rule the sand should require no preparation apart from washing, screening, and fine grinding. The washing may be necessary to remove clay, if any is present, but should be avoided where possible, as it also removes the finest and most active particles of silica.

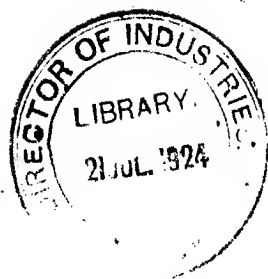
Quartz and flint are often heated to a high temperature and quenched in cold water to disintegrate them and facilitate the grinding. The grinding may be carried out in any suitable form of fine grinding-mill, the pendulum (l. 371), ball (l. 365), or tube mills (l. 369) being very suitable. Kieselguhr is prepared as described in Vol. I. p. 100. It is usually delivered to the user in the prepared state and needs no further treatment.

The purification of sand, flint, or kieselguhr by chemical methods, for use in chemical manufacture, is seldom advisable, it being preferable to purchase a material of the requisite purity for the purpose for which it is to be employed.

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Testing.—The only tests usually necessary for siliceous material to be used in the manufacture of chemical compounds are :

1. A chemical analysis to show the purity or otherwise of the material (I. 237).
2. A sizing or grading test (I. 246) to show the fineness of the sand.



CHAPTER XI

THE USES OF SAND IN POTTERY MANUFACTURE

THE term "pottery" may be understood to include all articles made of clay, with the exception of bricks (p. 1). In this broad sense, sand is used in pottery manufacture for the following purposes:

1. To reduce the plasticity and shrinkage of the clays used, particularly in the manufacture of tiles and coarse hollow-ware.
2. As a facing material, to improve the appearance of the ware.
3. As a constituent of the glazes applied to the surface of the ware.
4. As a coating for the floors of saggers and kilns, and to separate articles which might otherwise adhere to and so spoil each other.

The sand used for *reducing plasticity* and *contraction* of a clay should have the same properties as those mentioned in Chapter I. on the *Use of Sand in Brick-making*, but as even a small proportion of iron in the sand may have a harmful effect on the ware, it is usually necessary to employ a much purer sand than is needed in brick manufacture. The sand used for roofing-tiles and some red-ware, on the contrary, must contain sufficient iron compounds to have the requisite red tint when burned. Instead of white sand, very finely ground flint is commonly preferred by manufacturers of high-class pottery, as the silica in flint is amorphous and reacts more readily with any fluxes than do the small crystalline particles in sand. In addition to ordinary siliceous sands, geyserite (I. 175) has been used in the preparation of hard china and electrical insulators.

The sand used for reducing the plasticity and shrinkage of pottery must consist exclusively of very small particles. It should leave no residue on an 80-mesh sieve, but should not contain a large percentage of material which will pass through a 200-mesh sieve or the ware will be liable to crack.

The sand to be applied to *roofing-tiles* to give them a sand-face or antique appearance should be similar to that used for the same purpose on bricks (p. 6). It must, when burned, have a suitable and pleasing colour; the grains should be of medium size and

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should be sufficiently angular to adhere well to the clay to which they are applied.

For *glazes* the sand should have the same properties as those given in Chapter XII. on the *Use of Sand for Glass-making*, as the glazes applied to pottery, porcelain, etc., are of a similar nature to glass.

For use as a "*dusting*" or *parting agent* to be placed upon the floors of kilns, saggars, etc., the sand should be sufficiently refractory not to fuse and adhere to the ware placed upon it; the grains should be rounded and not too small. The high refractoriness requires the use of a high-silica sand, such as those used for silica bricks (p. 143) and glass (p. 194). The size and shape of the grains should be the same as in those of "*parting sands*" used in the foundry (p. 105), though for potters' use a rather coarser sand is often satisfactory. A sand which will leave no residue on a No. 2005 sieve but is retained completely on a No. 2000 sieve is usually satisfactory.

Sources of Sand.—The purposes for which sand is used in pottery are so varied that no one sand will do equally for all. Where the red colour of the ware is important a red-burning sand must of course be used. These are chiefly obtained from the same sources as the sands used for sand-faced bricks (p. 7), though a local sand should always be used where this is possible. For mixing with clay, etc., to produce white ware, a very pure sand or ground flint must be used, as even as little as 0.5 per cent of iron oxide will "stain" the ware. Such pure sands may be obtained from the same sources as those used for silica bricks. Much of the sand used for this purpose has been obtained by crushing silica rocks from the Millstone Grit formation at Mow Cop and Biddulph, but many other rocks, such as the Lower Greensands of Leighton Buzzard, King's Lynn, etc., and most of the purer sands are equally suitable.

It is seldom wise to use impure sands for white ware or high-class pottery, and although several patents have been granted for the use of waste sand derived from washing china clay as a substitute for flint in the manufacture of pottery, stoneware, porcelain, etc., such patents have little practical value. Sands from the same sources may be used in glazes and for separating the ware from the saggars, etc., in which it is burned.

Preparation of Sands.—The sands used in pottery manufacture are generally used in their natural state, the selection being confined to naturally suitable sands rather than to those which have been prepared in any way. When necessary, the sand may be washed (I. 384), dried (I. 401), and screened (I. 441).

Testing.—The sands used by potters are seldom tested prior to purchase. Actual use so rapidly reveals any defects, and the causes of these are usually so well known, that testing is commonly regarded as unnecessary. When unexplained defects arise, or when an improvement in the quality of the sand is desired, the most

important tests are: (a) a chemical analysis (I. 237) which will reveal the presence of any objectionable material; (b) a microscopic examination (I. 241) which will reveal the nature and shape of the grains; and (c) a fineness or grading test (I. 246) which will show the proportions of the particles of various sizes.

CHAPTER XII

THE USES OF SAND IN GLASS-MAKING

GLASSES are clear, transparent solids,¹ which are produced by the fusion of one or more materials. Their precise constitution is by no means clearly understood, and they may be either solid solutions of their various constituents or a homogeneous mixture of complex compounds. Each of these theories explains some of the properties of glasses, but neither is wholly satisfactory.

The simplest form of glass consists wholly of a simple substance which may be an oxide such as silica or boric oxide, or a salt such as sodium silicate; others are more complex and are formed by fusing several materials together.

So far as the use of sand is concerned, glasses may be divided into two kinds; namely, silica glass and alkali glasses.

Silica Glass² consists wholly of silica in the form of sand or crushed rock which has been heated to so high a temperature by means of an electric furnace or oxy-hydrogen flame that it has fused to a mobile liquid which takes the form of the mould in which it is melted or which may be "blown" or pressed to any desired shape. It is a special kind of glass used for refractory purposes and under conditions where a glass is required to withstand sudden changes in temperature. It is employed in the form of rods, tubes, plates, crucibles, muffles, saggars, retorts, evaporating dishes, combustion boats, ignition trays, lamp-glasses, and for other purposes where high, and especially variable, temperatures are encountered. It is also valuable as an electrical insulator at high temperatures, and is used for pyrometer tubes, thermostats, etc., and as a substitute for platinum and other refractory metals. Some quartz glass is quite clear and transparent, but most of it is only translucent, owing to the presence of large numbers of minute vesicles, many of which are filled with air. *Zirconia-quartz* or *Siloxide* is a fused mixture of silica and about 1 per cent of zirconia, which increases its strength; it is used for the same purposes as ordinary fused silica.

¹ Opaque glasses are better termed enamels, as they consist of glass with an opacifying medium in suspension in the glass.

² Further information on silica glass or fused quartz will be found in the author's *Refractory Materials: their Manufacture and Uses* (Griffin).

Alkali Glasses consist of a mixture of sand or crushed silica rock, with other materials, such as potash, limestone, soda, magnesia, baryta, zinc oxide, lead oxide, borie oxide, etc., which is fused at a temperature of about 1400°C ., and forms, when cold, a clear, transparent "glassy" mass, which may be either a solution of the materials used or may consist of one or more complex chemical compounds. Such glasses usually consist of soda, lime, and silica in proportions corresponding to a composition which is usually intermediate between $\text{Na}_2\text{O} \cdot \text{CaO} \cdot 6\text{SiO}_2$ and $5\text{Na}_2\text{O} \cdot 7\text{CaO} \cdot 36\text{SiO}_2$. More complex glasses containing other substances may correspond to such formulae as $6\text{K}_2\text{O} \cdot 2\text{PbO} \cdot 2\text{ZnO} \cdot 2\text{BaO} \cdot 36\text{SiO}_2$, or $3\text{Na}_2\text{O} \cdot 3\text{K}_2\text{O} \cdot 3\text{PbO} \cdot 3\text{CaO} \cdot 36\text{SiO}_2$.

Sand may be used to the extent of about 60 per cent of the mixture of materials forming the batch, which, when melted, forms the glass. The following are typical recipes for different kinds of glass:

Crown Glass.—Sand 100 parts, chalk 24 parts, sodium sulphate 50 parts, charcoal 4 parts, cullet (broken glass) 200 parts.

Window Glass (Sheet Glass).—Sand 100 parts, chalk 28 parts, sodium sulphate 42 parts, cullet 100 parts, arsenic acid 1 part, charcoal 3 parts, manganese dioxide $\frac{1}{2}$ part.

Plate Glass.—Sand 100 parts, chalk 30 parts, sodium carbonate 32 parts, potassium carbonate 6 parts, cullet 100 parts, manganese dioxide $\frac{1}{2}$ part, nitre 2 parts.

Flint Glass or Crystal.—Sand 100 parts, potassium carbonate 33 parts, red lead 67 parts, manganese dioxide $\frac{1}{2}$ part, potassium nitrate 7 parts, cullet 100 parts.

Baryta Glass.—Sand 100 parts, sodium carbonate 30 parts, barium carbonate 90 parts, red lead 65 parts.

Bottle Glass (Green).—Sand 100 parts, sodium sulphate 38 parts, chalk 33 parts, charcoal 2 parts, manganese dioxide $\frac{1}{2}$ part, cullet 50 parts.

Bottle Glass (Brown).—Sand 100 parts, sodium sulphate 35 parts, chalk 34 parts, cryolite 10 parts, charcoal 2 parts, manganese dioxide 8 parts, cullet 50 parts.

The Purpose served by Sand in Glass.—As most glasses behave like complex silicates, the silica in them plays the part of an acid radical in a complex salt, and where sand is used as the source of silica it plays the same part. Its action is purely a chemical one, and as in most cases the only useful constituent in it is the silica, it is of the utmost importance that the proportion of other constituents should be as low as possible. As silica is a poor conductor of heat, the smaller the particles the more rapidly will they become heated and the quicker will the glass be produced. Chemical reactions proceed at a rate which is closely connected with the amount of contact between the reacting particles, and consequently the smaller the particles of sand the more rapidly will the glass be produced. Large grains of sand, which are not readily attacked by the metallic oxides present in the mixture,

remain undissolved in the glass, forming "seeds" or "stones" which impair the transparency of the glass and render it useless for optical instruments.

Sources of Sands.—Transparent fused quartz is usually made from selected pieces of rock crystal, Norwegian quartz being specially useful for this purpose. The translucent fused quartz ("vitreosil") is made from fine white sand of the same quality as that used for the best glasses.

The sands used in this country for making other kinds of glass-ware were, prior to the war, largely from foreign sources, Fontainebleau sand being largely employed for the glasses of the best quality; sands from Holland, Germany, and other places were also used. During and since the War, when these supplies were cut off, various English sands have been used for glass-making, but more recently foreign supplies have again become available, and many glass manufacturers have reverted to the use of the sands which they employed prior to 1914.

The occurrence and distribution of glass sands in this country have been very ably investigated by Prof. P. G. H. Boswell,¹ who has found the following sources:

The geological distribution of glass sands is shown in Table XVIII. (I. 116). Glass of the best quality, such as fused silica, optical glass, plate glass, cut glass, etc., is made chiefly from the Lower Greensand beds of Lynn, Leighton Buzzard, Aylesbury, etc. (I. 118). The Greensand beds at Aylesford and Reigate (I. 118) might also be used for good glass-ware, though at present they are only used for bottles. The sands of the Tunbridge Wells (I. 121) and Ashdown beds (I. 121) are often very pure, but the transport of these materials is very difficult and costly, owing to their situation. The Estuarine beds of Huttons Ambo are sometimes sufficiently pure for glass-making, and some other deposits, such as the Eocene sands of Hampshire (I. 81) and the Triassic sands of Cheshire (I. 123) and Nottinghamshire (I. 85), might, if suitably treated, be used for this purpose. Boswell also suggests that some of the Pocket Sands of Derbyshire and Staffordshire (I. 134) might be used for some optical glass and for resistance glass-ware. The shore sands of Jura and Islay in Scotland (I. 158) might also be suitable for high-class ware. Window glass and other glasses of similar quality are made from the Glacial sands of Lancashire (I. 115) and the Estuarine sands of Huttons Ambo (I. 103). The Eocene sands of Hampshire (I. 81), the Kellaways sand (I. 123) in Yorkshire at Burythorpe and South Cave (I. 123), and some of the Trias sands of Cheshire (I. 123) might also be used for window glass if washed.

Bottle glass is made from the Glacial sands of Lancashire (I. 115), the Eocene sands of Hampshire (I. 81), the Thanet sands of Kent

¹ *British Resources of Sands suitable for Glass-making, with Notes on certain Crushed Rocks and Refractory Materials.* Two Memoirs. Longmans, Green & Co., London, 1916 and 1917.

(I. 163), the Kellaways bed at Burythorpe and South Cave in Yorkshire, the Estuarine sands of Huttons Ambo (I. 103), the Triassic sands such as those at Spital (I. 123), and various other less important localities. Bottles of better quality are made from the Lower Greensands of Aylesford and Reigate (I. 118). In Ireland, shore and dune sands (I. 157) are used, those found at Ardara (Co. Donegal), Ballycastle (Co. Antrim), Coalisland (Lough Neagh), the shores of the river Foyle, Millisle (Co. Down), Portrush (Co. Antrim), Rosslare (Co. Wicklow), Sandymount Strand near Dublin, Silver Strand near Wicklow, Sutton near Dublin, etc., being very suitable. Some Scottish dune and shore sands have also been worked for bottle-making (I. 158).

Various crushed rocks have also been suggested by Boswell as suitable for glass-making. He regards the best of these as that from Muckish Mountain (I. 140), which will give a colourless glass without any washing and may prove to be very valuable in the future. Other crushed rocks suitable for glass-making occur in Ireland at Achil Island (I. 140), Port-a-cloy (I. 40), Tinalahy (Co. Wicklow) (I. 39), etc.; and some Scottish rocks, such as the sandstones of the Millstone Grit (I. 153), Carboniferous limestone (I. 150), and Calcareous Sandstones Series (I. 151), and the Brora sandstones of the Middle Oolites (I. 58), appear to be suitable. Various other deposits have been suggested by Boswell for various purposes; further information concerning them will be found in his *Memoirs*.¹ Many of the sands in this country which cannot be used in their natural state would make high-class glass-ware if they were properly washed before use.

Geyserite (I. 175) from Germany has been used for the manufacture of glass, and it is stated that the use of 20-30 per cent of geyserite produces glass which is able to withstand sudden changes of temperature.

Chemical Composition of Sand.—The nature of the sand used for the manufacture of various kinds of glass varies considerably according to the glass to be made, but in all cases the sand consists principally of silica, and whilst it is generally in the form of a fine sand, it may be a crushed sandstone, quartzite, or other silica rock.

The best sand which could be used for glass-making would consist entirely of silica, as the purer the sand the better will be the glass. As a general rule, however, the sand used for the best-quality glasses contains about 99·5 per cent of silica, but may contain as much as 99·8 per cent. The best glass sands in the world are those which contain over 99·5 per cent of silica, such as the Fontainebleau sand (France), which contains 99·7 per cent of silica, Lippe sand (Germany), containing 99·8 per cent, and the Berkeley Springs sands (United States), containing 99·65 per cent of silica; some sands in this country are almost as good as this, as, according to Boswell, some of the Ashdown and Tunbridge

¹ *Loc. cit.*

Wells sands contain 99.5-99.8 per cent of silica, the Lower Greensand beds at Aylesbury contain about 99.5 to 99.8 per cent of silica, at Bearstead about 99.3 per cent, at Leighton Buzzard 99.6 per cent, and at Lynn 99.2 per cent, whilst the Huttons Ambo sand contains about 99.0 per cent of silica.

The rock crystal used for making transparent fused quartz-ware must contain at least 99.8 to 99.9 per cent of silica, because as little as 0.3 per cent of impurity will cause opacity. The purest glass sands are used only for the best quality, colourless ware such as fused silica, and for optical, crystal, and plate glasses. For commoner ware, such as window glass, bottle glass, etc., the percentage of silica need not be so high, some of the sands used for the manufacture of dark green bottles containing only 65 to 75 per cent of silica.

The *impurities* in glass-making sands are the same as in sands used for other purposes, but a very small proportion of impurities will prevent a sand from being used for glass of high-class quality. The most objectionable impurities in sand to be used for making glass-ware are alumina, iron compounds, vegetable and other organic matter and, to a much smaller extent, lime and other bases. Sands for use in the manufacture of the best glasses should not contain more than 1 per cent of all these impurities, and in most cases sands should be used with less than half this percentage of impurity.

Alumina occurs in glass sands principally as orthoclase or plagioclase feldspar, muscovite, and clay; the two latter may be removed fairly readily by washing, but feldspar cannot be removed in this manner.

In small proportions alumina is useful in sands used for making glasses which are to be exposed to pressure or heat, such as thermometers, ampoules, gauge glasses, combustion tubing, etc., as it reduces the coefficient of expansion and increases the hardness, brilliancy, tenacity, and strength, and renders the glasses more durable in use. On account of the reduction in the coefficient of expansion less care is necessary in the annealing process. Alumina also increases the surface tension when the surface of the glass is chilled, so that defects in the mould are less serious in the case of glass which is blown or pressed, whilst at the same time the latter is sufficiently plastic to acquire the required shape. When alumina is present in glasses containing much lime, it also tends to prevent their devitrification and reduces the solubility of the glass in weak acids.

Schott has suggested that alumina hinders the volatilisation of the alkalis at the surface of the glass, whilst Frink has found that glasses containing 3.4 per cent of alumina are less susceptible to the reducing action of the fire or to the formation of "cords," "strains," or laminations than those in which alumina is absent.

The chief disadvantages of alumina in glass-sands are:

(a) It decreases the fusibility of the glasses.

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(b) It appreciably increases their viscosity at working temperatures, if more than 3 per cent of alumina is present.

(c) Glasses containing alumina do not mix readily with others, so that they should not be used as cullet on account of the tendency to form "cords."

(d) Where salt-cake is used and alumina is present, there is sometimes a tendency to a slightly blue colour, due to the formation of an aluminium compound similar to ultramarine.

(e) As alumina usually occurs as clay or aluminosilicates, it is almost invariably associated with and introduces iron into the sand, which is usually undesirable.

Hence, from the preceding notes, the presence of alumina is often useful, but in optical glasses it is undesirable, as it tends to alter the optical constants of the resultant mass, and in such glasses not more than 0.5 per cent of alumina should be present. On the other hand, the sands used for making dark glass bottles often contain about 3.6 per cent of alumina, and fragments of Bridgewater bricks containing 16.4 per cent of alumina are sometimes added to increase the tenacity of the glass.

Iron compounds are undesirable in sands used for glass-making, but their presence is allowable to an extent which varies with the nature of the glass to be made. They usually occur either (a) as a film coating the grains of quartz and other minerals present, or (b) as grains of magnetite, ilmenite, etc., disseminated through the sand.

The occurrence of iron oxide in sands is more fully described in Vol. I. Chapter IV.

The effect of iron oxide in sands for making glass is to give the resultant glass a greenish or brownish colour, the depth of which depends largely, but not wholly, on the proportion of iron present.

Table LIX., due to Peddle, shows the effect of added iron oxide on the colour of the glass; the figures are, of course, only correct in the absence of a decoloriser:

TABLE LIX.—EFFECT OF IRON OXIDE ON THE COLOUR OF GLASS

Colour of Glass.	Ferric Oxide added.
Colourless	Less than 0.02 per cent
Nearly colourless	0.02-0.05 "
Faintly green	0.05-0.10 "
Yellowish green	0.1-0.3 "
Green	0.3-1.0 "
Dark green	1.0-2.0 "

As the sand itself only forms about two-thirds of the composition of the batch or mixture used for making glass, it will be seen that colourless glasses can only be produced from sands containing not

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more than 0.03 per cent of iron oxide, this proportion being reduced to 0.02 per cent in the resultant glass. In using Table LIX. to determine the proportions of iron oxide allowable in the glasses of various kinds, it should be remembered that the use of a de-coloriser such as manganese dioxide, nickel oxide, or selenium is permissible in many branches of glass manufacture, so that rather more iron is permissible in the sand than would otherwise be the case.

The best-quality optical glass should be perfectly colourless and the sand used in making it should not generally contain more than 0.03 per cent of iron oxide, whilst optical glasses containing barium and zinc compounds should preferably be made from sands containing not more than 0.02 per cent of iron expressed as ferric oxide. "Crown" optical glass, on the contrary, is often made from sands containing up to 0.4 per cent of iron oxide. Crystal glass, which is used for cut-glass work, should contain less than 0.04 per cent of iron oxide. Plate glass should contain not more than 0.05 per cent for the best qualities, though poorer qualities may contain up to 0.2 per cent.

Sands for mirror glass should contain not more than 0.1 per cent of iron oxide. For laboratory glass-ware a specially low percentage of iron oxide is not quite so important, and up to 0.05 per cent is permissible.

Bottle-glass sands may have a very variable proportion of iron oxide, which, according to the colour of the bottles desired, may be between 0.5 and 7.0 per cent, though about 1.5 per cent is regarded as the usual limit.

Lime and Alkalies.—The presence of lime and alkalies is usually undesirable in glass sands, though their presence does not often cause serious trouble. In optical glass, it is preferable to use sands which do not contain more than a total of about 1 per cent, as it is then possible to add just the substances required to make the glass without the unwished-for effects of other materials on the optical constants of the glass. In sands used for making other kinds of glass, the presence of lime and alkalies is not usually serious unless they are associated with iron compounds or other colour-producing substances.

Magnesia in more than unavoidably small proportions is always undesirable in glass-making sands, as it tends to make the glass viscous and "stringy"; occasionally magnesia compounds form insoluble fragments known as "stones," consisting of silicates or aluminosilicates of magnesium and lime, which do not fuse at the highest temperature attained in practice. These "stones" may be identified under the microscope, and should be avoided as far as possible.

Organic matter should not be present in the sands used for glass-making, as when the various materials are being heated and fused the organic matter chars and forms black spots which are not readily burnt out, though they can sometimes be oxidised by the

addition of nitre to the batch. A sand which is otherwise suitable may sometimes be freed from organic matter by washing.

The *moisture content* of a sand to be used for glass-making is not often important in the case of the cheaper kinds of glass, and in some cases wet sand is used. For the best qualities of glass, however, it is usually desirable to employ only dry sand, especially where the composition of the glass batch must be made up very accurately. A small proportion of "combined water" (I. 182) may occur in some of the minerals present, such as clay, mica, etc., but this is usually of minor importance.

Mineralogical Composition.—A sand to be used for glass-making should consist almost wholly of colourless grains of pure quartz. A very small percentage of *felspar* (I. 184) may be permitted, on account of the alumina it contains, but it must never be large enough to produce turbidity or opacity.

Clay (I. 182) is undesirable, and if present should be removed by washing the sand.

Heavy minerals (I. 203) are particularly harmful, as they tend to introduce iron compounds which spoil the colour of the glass. In sands used for the poorer qualities of glass, they may be present to a small extent without doing much harm.

Soluble salts, particularly sulphates, are very objectionable in sands used for the manufacture of the better qualities of glass, because they tend to make the glass turbid or even opaque and reduce its resistance to the weather. An excess tends to form a floating scum during the melting and hinders the classification or "fining" of the glass.

The **shape of the grains** of sand used in glass-making is not of great importance, as both rounded and angular grains may be satisfactorily employed. The only advantage possessed by angular grains is that for the same weight of sand they have a greater surface area than rounded grains, and so melt more quickly and should require less fuel; the difference is, however, scarcely perceptible.

The Fontainebleau, Dutch, and most of the British sands suitable for glass-making are all fairly angular; the Workshop sands, on the contrary, consist largely of rounded grains.

Size of Sand Grains.—When a sand is to be used for glass-making, the size of the grains is not so important as their uniformity, provided the sand is sufficiently fine. The manufacture of glass is essentially a chemical reaction in which the sand is one of the chief ingredients. As all chemical reactions proceed most smoothly and rapidly when the various reagents are in the most finely-divided state, it is obvious that the smaller the particles of sand the more suitable will they be for the manufacture of glass; there is, however, a limit of size below which mechanical difficulties occur. If the sand were ground to a fine dust, a considerable part of it would be drawn out of the melting pot or tank by the draught of the furnace, and the composition of the batch remaining behind would be thereby disturbed.

In addition to this, there is the great cost of grinding sand to dust, a cost which must be avoided as far as possible in the manufacture of the commoner kinds of glass. Another matter which has indirectly an important bearing on the size of the grains of sand used in glass-making is the fact that the smallest grains usually contain the chief part of the impurities in the sand, and by separating these very small grains a great improvement in the purity of the residual sand is effected. The reason why some glass manufacturers have reported that the smallest grains are unsatisfactory appears to be the presence of impurities in the sand rather than the smallness of the grains. A further disadvantage of very fine sand is that any surplus tends to remain in suspension in the glass instead of settling readily during the "fining" process, and consequently a turbid glass is produced.

For most kinds of glass the grains of sand may be of any size less than 0.025 in. in diameter, but the practical advantages, especially as regards the increase in the purity of the sand, which are secured by removing the smallest particles, are so great that it is not usually desirable to employ a sand containing particles less than 0.005 in. diameter. Where a narrower range of size is possible, either as a result of washing and screening or because an exceptionally uniform sand is available, it is still better to use a sand in which the largest grains do not exceed 0.012 in. diameter and the smallest ones are not less than 0.005 in. diameter. The use of particles larger than 0.025 in. diameter is undesirable, as they melt more slowly than the smaller grains and tend to leave "seeds" or unmelted particles in the finished glass.

Whatever limits of size of the sand are adopted, it is most important that all the grains should be as equal in size as possible. A uniform sand will melt more quickly and will produce a more homogeneous glass than one containing grains of numerous sizes, especially where stirring the molten glass is not permissible on account of the danger of contamination. Where the cost is not prohibitive, Peddle has suggested that a sand used for glass-making should consist of grains between 0.009 and 0.012 in. diameter.

Some of the best glass sands available conform very closely to the limits just mentioned. One of the most widely used, the Fontainebleau sand, has, according to Peddle, 79.6 per cent of grains between 0.009 and 0.012 in. diameter. The same investigator has stated that the sands of the Middleton bed of the Lynn sand and the Huttons Ambo sands are amongst the most uniform glass sands in the country. Table LX. shows an interesting comparison between various washed sands.

It will be seen that Lynn and Huttons Ambo sands are almost identical with Fontainebleau sand, and for the range 0.009-0.02 in. they are rather better as regards texture and melt rather more quickly.

Fused Silica-ware.—The siliceous rock used for making transparent quartz-ware is generally ground to the form of a dust or extremely

TABLE LX.—MECHANICAL COMPOSITION OF SANDS (Peddle)

Size, in Inches.	Fontainebleau	Huttons Ambo	Burythorpe.	Kennythorpe.	South Cave.	Muckish Mt.	Lynn Begg.	Aylesbury.	Dutch.	Workop.
Over 0.02	0.1	0.05	0.1	0.3	0.3	3.8	0.01	1.0	0.05	9.0
0.009-0.012	79.6	77.9	48.8	53.5	7.2	32.3	78.4	59.7	74.8	26.0
0.009-0.02	81.3	92.1	50.7	53.7	7.6	89.2	91.6	82.5	78.0	75.7
0.005-0.02	99.8	99.7	98.1	99.0	95.3	96.0	99.9	96.6	99.7	89.8
Less than 0.005	0.05	0.2	1.8	0.7	4.4	0.2	0.05	2.4	0.2	1.2

fine powder so that it can be melted very quickly. There is practically no limit to the fineness allowable, the conditions of manufacture being different to that of ordinary glasses. The sand used for the less transparent fused silica-ware made in an electric furnace should consist of grains of the same size as is used for glass.

Specification of Sands for Glass Manufacture.—For the production of the best qualities of glass, only the purest silica sands should be used. The iron, expressed as oxide, should not exceed 0.02 per cent, the alumina should not exceed 0.05 per cent, and all other oxides should not exceed 0.5 per cent. The grains should be colourless and as uniform as possible in size. Grains larger than 0.012 in. diameter and those less than 0.005 in. diameter should be absent.

For glasses of inferior quality the restrictions need not be so severe, and where dark-coloured glasses are to be produced low-grade sands rich in iron may be employed. Alumina in excess is harmful, and should be avoided.

Preparation of Glass Sands.—The nature and amount of preparation necessary for producing sands fit for glass-making depends chiefly on the kind of glass to be made. Common green bottles are often made from sand which is simply removed from the pit and weighed for use, no treatment being considered necessary. For chemical ware, plate and sheet glass, the sand should preferably be washed and dried. For crystal glass and colourless glass of medium quality the sand should be washed, dried, and sieved free from dust, whilst for the best quality of optical glass the sand should be first washed and dried, and then screened so as to exclude both very coarse and very fine material.

Grinding is sometimes practised in the preparation of sands for glass-making, and is essential where a crushed rock is employed. The disadvantages of this treatment are, however, that it increases the cost of production, there is a probability of spoiling the glass on account of the introduction of iron from the grinding plant, moisture is liable to be absorbed and may cause bad mixing, and

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the fine particles may produce a non-homogeneous melt. These difficulties can be overcome, but it is preferable, where possible, to use a sand which does not require crushing.

Rocks which need to be crushed to reduce them to sands are usually treated first in a primary crusher (I. 346) and then in an edge-runner mill with a stationary solid bottom pan (I. 375), or in one of the fine-grinding machines described in Vol. I. Chapter VIII. A very ingenious mill used in America consists of a stationary solid pan, with two screens in the sides of the pan and opposite to each other. Water is fed on either side. The tailings are returned to the mill at intervals, whilst the material which passes through goes to the washers. It has been claimed that a mill of this kind, with a pan 9 ft. diameter and rolls with a 12-in. face weighing 5000-6000 lb. each, will treat 100-250 tons of material every 10 hours.

Screening is very desirable in order to produce a sand of uniform grade. The coarse particles may be separated by means of a coarse screen, whilst either a fine screen or some method of washing may be employed to remove the finest grains. Sands which are screened are considerably improved both in physical texture and in chemical composition, as much of the impurities present are removed with the finest particles. According to Peddle, the effect of screening a sand is to improve the colour of the resultant glass by approximately one shade (*see* Table LIX. on p. 197) by the removal of the iron oxide, but the actual amount removed in this way must of course depend largely on the nature of the iron compounds present.

The beneficial effect of screening in removing some of the impurities in the sand should not be overlooked, as much of the iron, titanium, and aluminium compounds, as well as other heavy minerals (I. 203), may be removed by this means (Table LXI.).

TABLE LXI.—EFFECT OF SCREENING ON PURITY OF SAND *

	A.		B.	
	Before Screening.	After Screening.	Before Screening.	After Screening.
Iron oxide	0.0068	0.002	0.0114	0.0029
Titanium oxide . . .	0.117	0.024	0.024	0.00434
Alumina	0.276	0.085	0.366	0.106

* Annual Report of the State Geologist for the Year 1906, Geol. Survey of New Jersey, pp. 77-86.

It is frequently found that if a glass-making sand is screened so as to reject all particles smaller than 80-mesh, the quality of

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the resulting glass is greatly improved on account of the absence of the impurities which were chiefly present in the fine material.

Washing is by far the most effective method of improving the quality of sands employed for making very pure glasses, as the removal of iron compounds, clay, etc., is largely effected by this means.

Much of the iron compounds occur among the smallest grains of sand, and in many cases the proportion of iron compounds may be reduced by merely removing the finest particles of the sand, *e.g.* by washing. This is due to the fact that the iron is often associated with any clay which may be present, so that when the clay is removed the iron is also partially separated. Even with regard to the iron compounds not associated with clay, it will be found that, when in the form of grains disseminated through the sand, they are almost invariably much finer than the quartz-grains, so that they are largely removed by washing away the finest portion of the sand. Boswell has found that the iron, expressed as ferrie oxide, in the Leighton Buzzard sands may, by suitable washing, be reduced from 0.10 to about 0.06 per cent, whilst that in the Huttons Ambo sand has been reduced from 0.13 to 0.04 per cent. The proportion of iron, alumina, and other compounds in sands may also be reduced considerably by this treatment. According to Peddle, the effect of washing a sand is to improve the colour of the resultant glass by two shades (*see* Table LIX. on p. 197); where screening and washing are both employed, the resultant glass may be three shades lighter than that made from unwashed sand. These figures are only approximate and must not be applied too rigidly.

Where a sand contains a very adherent film of iron oxide or limonite, washing may not improve it to any great extent; in such cases, if the proportion of iron oxide is high, the sand should be rejected.

Washing also has the advantage of removing some of the finest particles of clay, organic matter, salts, etc., which might cause trouble when melted with the rest of the sand. The effect of washing in improving the grading of a glass sand is shown in Table LXII., due to Boswell.

TABLE LXII.—EFFECT OF WASHING ON SAND

Sizes of Particles.	0.046 to 0.02 in.	0.02 to 0.01 in.	0.01 to 0.004 in.	0.004 to 0.0001 in.	Less than 0.0004 in.	Total Sand Grade.
Port-a-cloy silica :						
Untreated . . .	2.6	55.6	29.8	8.1	3.9	88.0
Washed	49.7	44.7	4.5	1.1	94.4
Huttons Ambo sand :						
Untreated . . .	4.4	71.1	20.0	1.6	2.9	95.5
Washed . . .	1.2	97.0	5.6	0.5	0.8	98.7

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The methods of washing which may be employed are described in Vol. I. p. 384. Washers of the inclined screw conveyor type, such as the Freygang separator (I. 390), are very satisfactory for glass sands. Care should be taken not to allow the wash-water to flow away too rapidly or much valuable sand may be carried away and lost.

Chemical purification is sometimes useful, the methods employed being those described in Vol. I. p. 433. Boswell has mentioned an instance in which the iron content of the sand was reduced from 0.2 per cent to 0.03 per cent of iron oxide by treatment with nitre cake. Chemical purification is only valuable for sands which are to be used in the manufacture of high-class ware, as for common glass the cost of treatment is prohibitive.

Magnetic separation (I. 428) may sometimes be employed with advantage in purifying sands for use in special glasses, especially for the removal of metallic iron, magnetite, and other magnetic minerals. Rocks which have to be crushed to powder before use should generally be subjected to a process of magnetic separation, as they are liable to be contaminated with metallic iron during the process of grinding.

Drying is necessary in the case of sand for the best qualities of glasses, but wet sand is sometimes employed for making inferior grades. The extent of drying which is necessary depends on the nature of the glass-ware to be made. Sands are often merely drained, no artificial heat being used to dry them. Steam-pipe dryers (I. 409) in which the material is discharged on to hot pipes are sometimes used. Rotary dryers are very useful where the output is sufficiently great; for glass-making sands, enclosed rotary dryers such as the Ruggles Coles (I. 410) or Manlove Alliot type (I. 411) are preferable to those in which flames and waste gases come in contact with the sand, as there is less contamination by the flue gases. Stack dryers (I. 408) have also been used.

Testing Sands for Use in Glass-making.—The principal tests required to determine whether a sand is suitable for use in glass manufacture may be divided into two groups :

(A) *Tests of Purity :*

1. The colour of the sand should be examined both in its raw and calcined state, as this will give some indication of the purity of the sand.
2. A chemical analysis (I. 237) to show what impurities are present and particularly the percentages of iron oxide and alumina. For many purposes an analysis of the residue left after treating the sand with hydrofluoric and sulphuric acids (which remove the silica as a volatile fluoride) is preferable to an ordinary chemical analysis (see I. 203).
3. An elutriation test (I. 252) to determine the proportion of clay present.

4. A mineralogical analysis (I. 256) by means of a microscope, to determine the nature of the impurities present.

(B) *Tests of Texture :*

1. A microscopical examination (I. 241) to show the shape of the grains.
2. A sizing or grading test (I. 246) to show the proportions of grains of various sizes.

CHAPTER XIII

THE USE OF SANDS AS ABRASIVES AND POLISHES

ABRASIVES are used in innumerable industries for grinding and polishing leather, metals, hides, etc., for cutting, grinding, and polishing glass and stone, polishing and smoothing wood, ivory, and many other articles. In general, the grinding, smoothing, or polishing action is due to the rubbing of a hard abrasive material upon the softer article, with the result that the irregularities in the surface of the latter are worn down and smoothed over, until a sufficiently smooth surface is produced. In the final stages of polishing the abrasive may not be much, if any, harder than the article to be polished, and in some cases the abrasive is quite soft.

All abrasives are of the nature of either natural or artificial "sands," though some of them are not commonly included under this term. They are applied in various ways, the chief of which are:

(1) In the form of a loose, incoherent material, which may be either dry or wet, which is placed on some hard surface, such as a plate of iron or glass, and the material to be ground is rubbed upon it until it is sufficiently abraded, fresh sand being added as may be required during the process. This method is employed for grinding and polishing stone, metals, wood, ivory, leather, glass, etc. The powder is sometimes sprinkled on a wheel covered with suitable support such as felt, and the article to be polished is applied to the prepared surface of the wheel. This arrangement is specially used for very fine polishing and finishing metals, such as the buffing of silver plate, etc.

(2) In the form of a loose, incoherent powder, the particles¹¹ of which are projected with some force (*e.g.* in a blast of air at a pressure of 1-4 lb. per sq. in.) against the surface of the glass, stone, metal, etc., to be polished (Fig. 11). The innumerable impacts of the grains of sand against the surface, each impact producing a minute depression, gradually wears away the irregularities on the surface of the article and so smooths or polishes it. If, on the contrary, a polished surface is treated in this way it is immediately roughened. Thus, by merely allowing the sand to play on a sheet of glass for a moment, the glass is rendered opaque wherever the sand can strike it, and if the exposure were to be prolonged, holes

would be cut right through the glass. The advantage of this process, especially with brittle materials like glass, is that the erosion is carried out by an immense number of extremely small blows, each of which has no harmful action on the material as a whole, so that there is no danger of breakage such as would occur were the force applied in a more concentrated form, as in chipping glass or stone. This method of using abrasives, termed *sand-blasting*, is largely used for producing ground and frosted glass, for decorating sheets or objects made of glass with ornamental designs, labelling bottles, etc. Sand-blasting is also used for cleaning the scale off castings, and is very effective, as the abrasive penetrates all the recesses of intricate castings without disturbing the shape. It is also useful for cleaning castings, prior to galvanising, tinning, or plating; formerly, this was done by pickling in

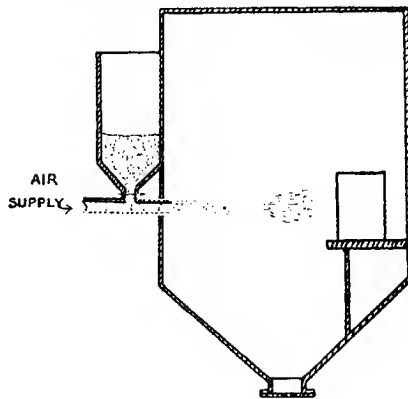


FIG. 11.—Diagram of sand-blast apparatus.

acid, but sand-blasting is far more effective and quicker. A sand-blast may be used for re-sharpening files, the sand being applied to the back of the teeth for about 3-5 mins., so as to cut away the metal and form new cutting edges.

3. In the form of a powder which is mixed with glue or other suitable adhesive and applied to the surface of strong paper, cloth, leather, etc., in such a manner that the grains of sand project from the surface of the material and form an abrasive surface. This method is employed chiefly for the medium and fine polishing of metals, wood, etc. For fine polishing, the paper or cloth may be mounted on the sides or rim of a wheel, which is then revolved and the article to be polished applied to it.

4. In the form of a block, wheel, disc, cylinder, ring, roll, plate, or cup, composed of sand particles united by means of shellac, rubber, clay, or other suitable binding material. The blocks may

be applied to the article to be abraded or *vice versa*, but the wheels, etc., are mounted on a shaft and rotated, the article being applied either to their faces or edges. This method is largely employed for grinding metals.

5. In the form of a polishing paste or liquid, consisting of an adhesive powder suspended in a suitable medium, with or without a detergent to assist in removing any dirt or grease. This mode of using abrasives is largely employed for cleaning and polishing metal surfaces, the sand or its equivalent acting as a detergent as well as an abrasive, as in the metal polishes so largely used for cleaning brass, etc. It should be remembered that all polishes are not abrasives; some contain no abrasive and produce a gloss or polish by filling any small hollows in the surface and coating it with a shining film of wax or other glossy material.

6. In the form of an abrasive soap which consists of an ordinary soap mixed with abrasive sand, so as to increase its detergent



McEwen, Denby & Hart-Briggs, Ltd., Sunbury-on-Thames.

FIG. 12.—Abrasive wheels.

properties. Many cleaning powders and “dry” soaps sold under fancy names are of this type.

Abrasive Materials.—The following are the principal “sands” which are used as abrasives:

Silica in various forms is used as an abrasive, either as a loose sand applied to paper or cloth, or as a compacted block such as a sandstone. In each case, however, the action is due to the sand and depends on the rubbing of the particles of quartz. Siliceous sand or powdered quartz is used for cutting stone, marble, or glass, the sand together with water being fed on to the edge of a metal wheel which scrapes and presses the sand particles over the surface of the stone, etc., and so cuts through it. It is also used for grinding marble and other stones, glass, metals, etc. Sharp sand is used on a horizontal revolving iron plate for grinding terra-cotta, sanitary ware, and other ceramic articles.

The silt used in making *Bath Bricks* (I. 159) is a sandy material which is moulded into small bricks which are burned at a dull red heat and used for cleaning various domestic articles and for roughly polishing metals.

Siliceous sands are used (i.) loosely, (ii.) in the form of glass, and sand-paper for smoothing wood, leather, etc., (iii.) mixed with soap and used for scouring purposes, loose silver sand and crushed quartzites being also used for this purpose, (iv.) sometimes in the form of a sand-blast, for etching and decorating glass, cleaning, and surfacing metal castings, etc. (see p. 206), but for the latter purpose the sand is sometimes replaced by finely-powdered steel shot, and (v.) in the form of blocks, wheels, etc., such as hones, oilstones, millstones, etc., chiefly for grinding metals. On account of its inferior hardness, sand is being displaced for many purposes such as stone-cutting, grinding, etc., by aluminous and carbide abrasives which are more effective and cheaper to use. Whilst sand can only be used to a small extent directly as an abrasive, it is one of the chief ingredients in the valuable carbide abrasives.

Oilstone sand (I. 131), produced by grinding oilstones, is a siliceous abrasive which is chiefly used for grinding and polishing brass fittings, such as mathematical and optical instruments.

Chert (I. 175) is sometimes used as an abrasive, though generally in the form of blocks and not as a powder.

Rottenstone (I. 146) is a siliceous abrasive which is used for cutting and polishing glass, metals, etc., and also as an ingredient of metal polishes. It is also used for cutting colourless precious stones and for the first stages in polishing stones such as jasper, agate, etc.

Kieselguhr (I. 96) is a siliceous abrasive similar to rottenstone in texture; it is used chiefly for polishing metals, glass, and precious stones, and for making metal polishes. It has also been employed as a dentifrice.

Tripoli (I. 165) is a variety of kieselguhr and is used for the same purposes.

Pumice powder (I. 137) is a siliceous abrasive which is employed for cleaning wood, stone, and metal, for domestic purposes and also for the rough polishing of glass, stones, ivory, and metals, and for smoothing oilcloth. It is occasionally used as a dentifrice, but is too powerful to be satisfactory for this purpose.

Alumina in certain forms is a very powerful abrasive and is very valuable. It occurs in nature as *emery* (I. 101) and *corundum* (I. 93) and is also made artificially under various trade names, including *adamite*, *aloxite*, *alundum*, *borocarbone*, *corubin*, *oxyalumina*, etc., which are much harder and so give better service than the natural abrasives. They are used in the form of powder for grinding and polishing glass, gems, metals, edge tools, parts of firearms, etc.; and in the form of blocks they are used as sharpening stones for edge tools of various kinds. Aluminous abrasives should preferably be employed for materials having a high tensile strength, such as steels and hard bronzes, as aluminous abrasives are not so likely to splinter when applied to such materials. Aluminous abrasives are also used for some softer materials such as rubber, celluloid, etc.

Silicon carbides and *carboxides* are very valuable abrasives

produced artificially and sold under various trade names such as *carborundum*, *crystalon*, *carbositite*, *electrolon*, *fibrox*, etc. (see I. 86). Carbide abrasives are now largely used, both in the form of powder and as wheels, etc., for surfacing, slotting, and moulding metals, stone, and marble, for mitre-cutting, checkering, lacing, fluting, and beading glass, and for smoothing and bevelling the edges of lenses and for cutting and grinding hard rubber, fibre, etc. Glass is sometimes polished with very fine carborundum which has been specially treated with hydrofluoric acid and mixed with oil. Carbide abrasives are preferable for metals of low tensile strength, such as cast or chilled iron, brass, soft bronzes, aluminium, copper, granite marble, leather, and wood, as they tend to splinter with materials which wear away only under great pressure.

Diamond is the hardest material known, having a hardness of 10 according to Mohs' scale, and is an extremely valuable abrasive, especially for very hard materials. Diamonds are often mounted on the circumference of copper or cast-iron wheels so that they project like the teeth of a saw, or they may be mounted on a metal slide which is given a reciprocating motion. They are used for cutting gem stones and other hard minerals. In the form of a very fine sand or dust, they are used with oil for cutting and polishing gems and precious stones.

Garnet sands are chiefly used in the form of abrasive papers or cloths for smoothing wood and other fairly soft materials, as garnet is not so hard as quartz and artificial abrasives. Powdered garnets, embedded in shellac on the circumference of a wooden disc, have been used for ages in India, long before such wheels were known in Europe. They are also used in the form of blocks, bonded with shellac, by Indian coppersmiths and silversmiths for preparatory polishing processes.

Iron oxide sometimes occurs as a sandy or earthy material, which leaves, when the coarser particles have been removed, a material known as *rouge*, though the greater part of the rouge now used is prepared artificially. It is soft and capable of giving a very high polish to metals, glass, etc. *Crocus martis* and *glassite* are other forms of iron oxide which are also employed as mild abrasives and polishes.

Crushed steel and *angular grit* are not strictly sands, though they have similar properties and so may be mentioned here. Crushed steel is steel powder, whilst "angular grit" is prepared from chilled iron. They are largely used in America, one form of crushed steel which is made at Pittsburg being known as "diamond steel emery." "Angular grit" is largely used in place of sand for sand-blasting.

Other abrasives which are not strictly sands, such as lime, whiting, chalk, putty powder (tin oxide), manganese dioxide, etc., are used for fine polishing, but these do not come within the scope of this volume.

Essential Properties.—The principal qualities required in an

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abrasive or polishing sand, in whatever form it is used, are:
(1) Durability, (2) rapidity of action, (3) uniformity of action, and
(4) finish.

Durability.—An abrasive or polishing sand is required to grind the surface of other materials and remove projecting particles from them, but in doing this the sand itself must not be worn away excessively, or the cost of using it would be excessive. The durability of a sand under such circumstances depends upon (a) its hardness (p. 213), (b) its toughness (p. 216), and (c) the proportion of the total area of the grains which are available for abrasive or polishing purposes, as any abrasive material which remains embedded in the glue or other adhesive or binding material is useless so far as abrasion is concerned. The advantage of using a loose, incoherent sand for grinding is that the whole of the surface of the grains takes part in the abrasive action, whereas in emery cloth or abrasive wheels, only the exposed part of the grain has an abrasive action, and when this is worn down the remainder of the grain cannot be used on account of its position.

Rapidity of action is obviously of commercial importance, and the best abrasives and polishes do their work at the maximum rate. The factors connected with the sand which enter into consideration are (a) hardness of the grains of abrasive material (p. 213), (b) their toughness (p. 216), (c) shape (p. 216), and (d) size (p. 217). Other factors, not directly connected with the abrasive, which influence the speed of grinding include:

1. The speed with which the article to be ground moves over the abrasive, or *vice versa*. This factor introduces the force of impact, which is dependent on (a) the pressure exerted in the case of articles rubbed on loose powders or applied to a wheel, (b) the peripheral speed in the case of wheels or the like, (c) the speed at which the abrasive travels, (d) the grip of the adhesive on the grains, and (e) the number of impacts in a certain time, which is also dependent on the speed at which the abrasive and article move over each other in the case of loose powders or wheels, and the speed of travel in the case of a sand-blast.

2. The pressure at which the article to be abraded is applied to the abrasive material, or *vice versa*. Where the pressure is high (within certain limits) the speed of grinding will be increased.

3. The rigidity of the grains, *i.e.* whether they are able to "give" during service; this factor varies greatly. In the case of a wheel or similar appliance, there is a maximum rigidity, as both the article and the grains of abrasive are rigid and unable to "give." In the case of a sand-blast the grains are able to slip to some extent, and when loose powder is rubbed on the article, or *vice versa*, the slip is considerable.

4. The ease with which the abraded particles escape from the seat of abrasion. This is important, especially in the case of grinding wheels, as where such particles do not escape, they clog or "glaze" the wheel and so reduce the speed of grinding.

5. The hardness or resistance of the material to be abraded, which may be so similar to that of the abrasive that grinding proceeds too slowly to be practicable. These latter factors must be dealt with in the manufacture of the abrasive wheels or in the design of the abrasive machines and are not functions of the sand, so that they do not come within the scope of this volume.

Uniformity of action is very important, no matter whether the sand is used as a loose powder or in the form of an abrasive paper, block, wheel, etc., as if part of the abrasive has a different abrasive power from the remainder the effect on the material to be ground or polished will be irregular. Uniformity of action depends chiefly upon (a) the hardness of the grains, (b) their toughness, (c) their shape, (d) size, and (e) grading.

Finish.—A certain smoothness or "finish" is required upon articles which have been abraded. It varies according to the material being ground and the purpose for which it is to be used, and is dependent upon many factors. Those connected with the sand are the (a) hardness, (b) shape, (c) size, and (d) grading of the abrasive grains, but many other factors also enter into the problem. Thus a grain of given size coming into contact with the article to be ground or polished at a greater velocity will give a finer finish than another grain at a lower velocity. A low pressure will also give a finer finish than a heavy one.

From the foregoing statements, it will be seen that the principal requirements of abrasive sands are dependent on the following properties of the material: (1) Hardness, (2) toughness, (3) shape, and (4) size of grains, the latter including the grading of the material.

The chemical composition of abrasive sands is not directly important in itself, but it may help to decide their value in comparing different varieties of the same abrasive.

A siliceous sand for use as an abrasive should be as pure as possible, as the presence of minerals other than quartz will result in a lack of uniformity in the abrasive action of the material and usually in a reduction in the hardness of the abrasive. In some cases, the impurities may "smear" the grains and prevent them from doing their work.

Pumice and rottenstone may sometimes contain felspar grains, which are very undesirable, as they cause scratches in the polished surface produced by the fine abrasive. This is partly due to their being larger than the particles of abrasive. This is referred to later.

Aluminous abrasives may be judged by the percentage of free crystalline alumina they contain, as all other constituents are softer than alumina and, therefore, undesirable. Natural emery seldom contains more than 77 per cent of crystalline alumina and is, therefore, less valuable than artificial corundum, which may consist of practically pure crystalline alumina.

Lime compounds are very undesirable in hard abrasives, as they are much softer and reduce the efficiency of the latter. Lime

is, however, extensively used alone as a mild abrasive or polishing agent, particularly for silver.

Carbide abrasives should be as pure as possible and should not contain any of the original ingredients in the free state, as this would reduce the abrasive power of the material as well as reducing its uniformity of action.

Other abrasives should be as pure as possible, so as to consist of one material only and so effect a uniform abrasion.

When a sand or other abrasive is made into a block, wheel, or similar article, the presence of other materials apart from the principal grinding agent may be essential and sometimes an advantage. Thus, whilst the iron oxide in emery reduces the value of the material as an abrasive it does serve as a bond in making emery wheels, so that in some cases it is not entirely useless. As a general rule, however, the purer an abrasive the greater will be its value, as the required amount of bond can be added if the abrasive is to be used in the form of a block, wheel, etc.

The abrasive "sand" must not be poisonous, or the workers, who can scarcely avoid inhaling some of the dust, may quickly contract a fatal illness. For this reason, the use of some powders, such as tin oxide (putty powder), is now prohibited.

It is very desirable that an abrasive should not be affected by contact with water, as the latter is very useful in expediting the grinding and in catching much of the dust produced. It is usually the bond, and not the abrasive, which is affected by water.

The mineralogical composition of an abrasive sand, as distinct from its chemical composition, is important, as substances of similar chemical composition often differ very greatly in their physical properties; for example, corundum and diaspor would each show practically 100 per cent of alumina on analysis, but the latter is far softer than the former and of little value as an abrasive.

Siliceous abrasives should consist, as far as possible, entirely of particles of quartz, except in the case of rottenstone, kieselguhr, diatom-earth, etc., where cellular silica is the predominant form. Aluminous abrasives should, as far as possible, consist only of crystals of corundum, whilst carbide abrasives should contain only crystals of silicon carbide or carboxide. Any other minerals present are usually impurities and in all probability have a different hardness and are, therefore, detrimental. To ensure uniformity of action and a good finish, all abrasives should, as far as possible, consist of one mineral variety.

Hardness.—An abrasive material must usually be harder than the article or substances it is required to abrade, though this statement does not apply to some fine polishes; it is true of all coarser abrasives. The harder an abrasive: (a) the more rapidly will it abrade materials softer than itself, (b) the more resistant will it be to wear, and (c) the coarser will be the surface produced, on account of the deeper scratches formed.

The hardness of an abrasive for any particular purpose should depend on the nature of the material to be abraded. Soft materials such as wood, ivory, leather, etc., do not require an abrasive of great hardness, though hard abrasives may be more efficient. Hard materials such as steel, glass, gems, etc., require a very hard abrasive, otherwise the wear would be excessive and the durability of the abrasive would be very low.

The most valuable abrasive materials have a hardness between 9 and 10 on Mohs' hardness scale, though many other abrasive materials of inferior hardness are employed. Table LXIII. shows the hardness of the ones commonly used.

TABLE LXIII.—HARDNESS OF ABRASIVE MATERIALS

	Hardness (Mohs' Scale).
Diamond	10
Carborundum	9.5
Artificial corundum	9.5
Natural corundum	9
Emery	9
Spinel	8
Quartz and Flint	7
Garnet	6.7.5
Felspar	6.0

It will be seen that diamond is the hardest known abrasive and, on account of its hardness, is used for abrading the most difficult materials, such as glass and precious stones, which cannot be satisfactorily treated with any other type of abrasive. Carbide abrasives such as carborundum are the hardest artificial abrasives, but they are not so hard as diamond. Artificial corundum and other aluminous abrasives are slightly inferior to carbide abrasives in hardness, but they are harder than the natural minerals, corundum and emery, and consequently are more efficient. Of the natural abrasives corundum and emery are the hardest and therefore the most satisfactory, whilst sand, garnet, and felspar are used for purposes where a softer abrasive is satisfactory.

The abrasives used for polishing, such as pumice, kieselguhr, tripoli, rouge, etc., are still softer, and cannot be used for grinding on account of their low abrasive power; they are very valuable for giving a fine finish to surfaces which have been ground to a moderate degree of smoothness with harder abrasives. It is very important to test the hardness of samples of abrasive, especially natural abrasives, because the chemical composition of an abrasive does not necessarily prove that it is satisfactory. Thus, compared with Indian sapphire, which may be represented by a hardness of 10,

Canadian corundum has a hardness of 9·4, whilst some American corundum has a hardness of 5·8.

A factor which must be carefully considered in addition to great hardness is uniformity of hardness. Artificial abrasives are almost always uniformly hard, as there are practically no impurities present if the original ingredients were reasonably pure and the process of manufacture has been well arranged. With natural abrasives, however, uniformity of hardness is not so readily obtained. The effect of grains of varying hardness is well illustrated by natural emery, which consists of about 50 per cent of alumina and 50 per cent of magnetic iron oxide. The alumina grains are powerful abrasives, but the iron oxide has a very low abrasive power and so clogs up the other particles. Corundum is a purer form of alumina than emery and contains up to 96 per cent or even more of alumina. It is consequently a more uniformly hard abrasive. It contains, however, a certain amount of softer material such as felspar, hornblende, mica, garnet, etc., which reduce its value, though not to the same extent as emery, as the proportion is much smaller.

Siliceous sands do not usually act very uniformly as abrasives, because some of the minerals they contain are very hard, whilst others are much softer. This is specially harmful in fine work, as a strong particle of excessive hardness may cause a deep scratch in a polished surface and so necessitate extensive repolishing. For this reason, they are not used to so large an extent as some of the artificial sands, which are much more uniform in hardness. Thus, a siliceous sand consisting almost wholly of angular grains of pure quartz will be of more value as an abrasive than a less pure sand even though the latter may contain harder constituents, because it will give a more uniform abrasive action, whereas the less pure material will be irregular, especially in polishing.

Pumice sand or powder tends to be irregular in its abrasive qualities, on account of the presence of particles of harder minerals, such as felspar, etc., which scratch instead of polishing.

Whilst uniformity of hardness has been emphasised in the preceding statements, there are certain cases where mixtures of materials of different hardness may usefully be employed, such as where a fine finish is required in one operation. The harder particles quickly grind down the surface to the required extent, whilst, at the same time, the softer particles polish it; natural emery, with its contained iron oxide, is an example of this, and it is very often preferred for precision work, such as gauge grinding, on account of the polishing effect of the iron oxide which it contains. Aluminous or carbide abrasives grind more quickly and more efficiently than natural emery, but they do not give the same finish to the work.

Hardness is chiefly of importance in the case of the coarser particles, as fine abrasives for polishing, etc., need not be so hard. Some have a hardness of only 3 or 4 according to Mohs' scale and

arc, in fact, much softer than the articles or substances which they polish.

It is always desirable to use the hardest abrasive consistent with the finish required and with cheapness. In some cases an inferior abrasive may be preferred to a harder one on account of its cheapness.

Grade of Wheels, etc.—The effective hardness of abrasives when made up into the form of a wheel is termed the *grade* of the wheel, and is designated by a letter, the softest wheels being H and the hardest T. Wheels of grade O are the hardest commonly used, those such as grades S and T being employed for special purposes, such as removing the burr left by welding, the sharp lines from castings, etc. The grade of a wheel depends partly on the hardness of the abrasive and of the bonding agent, as well as on the speed of rotation of the wheel. Thus, a soft wheel will have the effect of a much harder one if it is rotated at a higher speed.

Toughness.—The toughness of an abrasive is very important and has a great influence on the durability of the grains, both when loose and also when in the form of paper, cloth, blocks, wheels, etc. The toughness (apart from hardness) usually depends upon the internal structure of the abrasive. Carborundum has a laminated structure; consequently, when great pressure is exerted on the crystals, they break sharply on account of their brittleness, so that if used on very hard materials, carborundum crystals wear somewhat rapidly; for this reason, they are not largely used upon materials of high tensile strength (p. 210). Highly siliceous materials are open to the objection of breaking too readily, and this, combined with their comparative softness, renders their use somewhat limited.

Corundum is preferable to carborundum because it is less brittle and does not fracture readily, but has a tough, granitic structure and preserves its sharp edges very satisfactorily and does not wear so rapidly as carborundum. Alundum, which is a form of artificial alumina, is one of the toughest abrasives known.

The sudden chipping of the grains of abrasive is not merely inevitable, but even desirable, so long as it produces new abrasive surfaces to replace those which are rounded and worn smooth (see also *Shape*, below); it is the excessive amount of breakage which is objectionable.

Shape.—Two factors must be considered with reference to the shape of abrasive particles: (a) the shape of the original particles, and (b) the shape of the particles after considerable use. The grains when new must be sharp and angular, and they must remain so, as rounded grains lack cutting or abrasive power. For the same reason an abrasive will be of little use, even if it is tough, if it forms rounded surfaces when worn, whereas another abrasive, which may be less tough, will be superior if the grains break at intervals, yielding fresh sharp edges which continue the grinding operation without any change in the speed of grinding or any tendency to "glaze." One great advantage of carborundum which

counterbalances its brittleness is the fact that when the grains break they yield sharp, angular points, so that the material remains perfectly free-cutting and does not deteriorate in use. Artificial abrasives are generally more uniformly angular than natural ones. Thus, natural emery and corundum are not so uniformly sharp and angular as artificial aluminous abrasives.

Siliceous sands are less satisfactory than some artificial abrasives for grinding metals, as they tend to break with a conchoidal fracture which has little abrasive action.

The nature of the fracture is less important if the abrasive material is very hard. Thus, diamond breaks with a conchoidal fracture, but as it is the hardest mineral known, its lack of angularity is not detrimental. For fine abrasives, composed of very small grains, the latter should not be unduly angular or they will scratch excessively; they should preferably be rather globular or sub-angular, with numerous facets or angular faces.

Apart from the angularity of the particles, the faces should be as rough as possible, as in natural emery, the grains of which are quite rough. This is particularly useful where the particles are to be made into a block or wheel, as the binder adheres more tenaciously to them and a much stronger mass is produced.

One of the difficulties with artificial abrasive sands is that whilst they are angular, they have smooth surfaces, but their other advantages more or less counterbalance this defect. When required, the surface of the grains can be roughened artificially by heating them with fused nitre cake (sodium hydrogen sulphate) and afterwards washing them free from this salt.

Size.—The size of the abrasive particles is important. For coarse grinding, the grains may be quite large, *i.e.* up to $\frac{1}{4}$ -in. diameter, these giving a much greater speed of cutting than very small grains. For finer work, however, a material composed of smaller grains must be used, so as not to scratch the surface excessively. The fineness of the abrasive, or "grit," as it is usually termed, must in each case be decided by the material to be treated. Coarse particles are more powerful abrasives than finer ones and are consequently used for rough work, but they would scratch and spoil finer work. For reasons of cost, it is desirable to use as coarse an abrasive as circumstances will permit, so that the work may be done as rapidly as possible.

The depth of cut of an abrasive, and therefore the rapidity of the grinding or polishing, depends largely on the size of the particles. Where the grains are united to form a grinding wheel, the depth of cut may be as much as about one half the diameter of the grains. In no case would it exceed this, as when a grain projects more than half its diameter, it falls out so easily as to be useless. Under as nearly ideal conditions as possible, the maximum depth of cut when using a wheel of 80 grit would be 0.001 in.; with 24 grit it is about 0.003 in., the particles of abrasive being 0.006 and 0.021 in. diameter respectively. When the abrasive is in the form of a loose powder,

the depth of cut is much less, but it cannot be accurately estimated.

In centrifugal grinding wheels, the coarsest permissible grains are desirable, as the grains can then be set more deeply and firmly in the bond, and therefore have a deeper cutting power, and the wheel has a greater strength; it can, therefore, be revolved more rapidly without becoming soft.

The coarseness of the grains of abrasive affects the number of impacts made by the particles upon the material to be abraded in a given unit of time. According to J. J. Guest, a wheel consisting of grains which will pass through a 60-mesh sieve has 1500 points per sq. in., though the Norton Co. give the number as 3300. A 24-grit wheel will have, according to J. J. Guest, about 256 points per sq. in.

All the grains of an abrasive sand should, as far as possible, be of the same size, so as not to scratch the material which is being ground or polished. In some cases, however, an abrasive may be required to consist of particles of various sizes, as in "combination" wheels made with a "mixed grit." (When the particles are the same size, the term "straight grit" is applied to them.) A wheel composed of 24, 36, and 60 grit is termed a 24 combination grit. It is very difficult to produce good combinations of various grits, and the mixtures generally used are trade secrets, and are designated in various ways. The advantage of a "mixed grit" is that the coarse particles grind the articles rapidly and the finer particles remove the scratches, polish the surface, and impart a finer finish than would otherwise be obtained.

Fine abrasives for polishing should, as far as possible, be uniform in size, and for the finest polishes the abrasives must be very carefully elutriated so as to ensure this.

The fineness or "grit" of an abrasive is generally designated by a number which is the same as the number of meshes per linear inch through which the grains will pass (thus, a No. 10 grit material is one which passes completely through a sieve having 10 holes per linear inch), or by a letter such as OO or FF (see p. 224 later).

As has been already mentioned, in selecting the "grit" of an abrasive, due consideration should be given to the purpose for which it is to be used.

Table LXIV., compiled from information supplied by some of the leading makers of abrasive wheels, shows the fineness required for various purposes when the particles of abrasive are united to form a *grinding wheel*.

In the form of a loose powder, abrasives of almost any fineness may be used, but the coarser particles are not usually so satisfactory when employed in this way. In the form of wheels, abrasives as small as 200-mesh may be employed, but smaller grains are not generally desirable. In the form of blocks, such as sharpening stones upon which the article to be abraded is rubbed, fine abrasives down to those designated as FFF may be used.

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TABLE LXIV.—SIZE OF ABRASIVE GRAINS FOR GRINDING VARIOUS MATERIALS

(The figures are the grit size, as defined on p. 218)

Purpose.	Alundum. ¹	Crystolon. ¹	Carborundum. ²	Emery. ³	Emery. ⁴	Emery. ⁴
Agricultural implements, edgings	..	..	..	16-20	16-21	16
Aluminum castings, grinding	36-16	20-21	16-21	..	..	..
Axles, grinding ends of	..	..	16-20	20-36	..	..
surfacing	..	..	..	20-36	..	..
Bolts, finishing heads of	..	..	..	36-60	..	..
Brass castings, large	..	20-24	16-21	16-21	16-30	30
small	..	24-36	21-36	30-36	..	..
finishing	..	..	..	60-100	..	..
Brick, fire-	..	16-20	11-16	..	..	..
pressed	..	16-20	14-16	..	..	..
Bridge work (wrought iron), jointing	..	..	..	16-20	..	..
Bronze castings	..	20-36	20-30	20-30	16-30	20
Car boxes (brass)	..	..	..	30-36	..	..
Carriage hubs, rim bands of	..	..	..	36-16	..	..
Cast iron castings, large	16-20	16-21	..	..	16-24	..
small	24-30	20-30	..	..	..	..
roughing	..	..	16-24	..	..	..
finishing	..	..	60-80	..	..	..
surfacing	20-16	16-30	16-24	16-30	..	..
Chilled iron castings	20-30	20-30	20-24	20-30	16-24	16
Couplings, car	..	..	..	14-20	..	..
Cylinders, cast iron	24 comb.	30-16	24-60	..	..	..
Dental instruments	..	..	..	46-100	..	..
Die, chilled iron	..	20-30	24-60	..	..	..
steel	36-60	..	30-36	..	..	..
surfacing	..	..	..	20-46	36	..
Drills, twist (hand)	46-60	..	16-60	..	46-60	46
(machine)	30-60	..	10-50	46-60	30-46	16
Drop forgings	20-30	..	20-36	20-30	16-24	30
Piles, edging	..	..	24-30	30-60	..	..
Progs, grinding	14-16	..	..	..	..	..
General machine shop grinding	..	..	20-30	20-36	24-36	30-36
German silver	..	..	..	80-120	..	..
Glass, rough edge grinding	..	..	100-120	..	..	..
finish edge grinding	..	..	200-FFF	..	..	..
Guards, pointing and sharpening	..	..	..	24-36	..	..
Hammers, cast steel	30	..	..	30-36	..	..
Hinges and butts	..	..	..	20-30	..	..
Hollow-ware, inside grinding	..	30	..	36	..	..
thin edges	..	21	..	20-30	..	..
Internal grinding, roughing	..	..	..	24-46	..	..
finishing	..	..	..	60-100	..	..
Knives, general	..	..	..	..	36-60	..
leather shaving	60	..	50-70	..	..	..
splitting	24-30	..	..	90	..	..
mower, sharpening	..	..	..	46-60	..	..
moulding bits, etc.	46-60	..	36-50	..	..	..
planer (machine)	30-46	..	20-36	..	24-36	30
(hand)	46-60	..	36-50	..	..	..
paper (machine)	36-46	..	202-203	30-36	24-36	30
reaper, sharpening	..	..	..	46-60	..	..
shear	30-60	..	24-30	36-60	..	..
shoe	60	..	..	70-90	..	..

¹ Norton Co.'s recommendations.

² Safety Emery Wheel Co.'s recommendations.

³ Carborundum Co.'s recommendations.

⁴ American Emery Wheel Workers' Table.

TABLE LXIV.—Continued

Purpose.	Alundum. ¹	Crystolon. ¹	Carborundum. ²	Emery. ³	Emery. ⁴	Emery. ⁴
Lath centres . . .	40-120	..	60-80	60-80	..	..
Lawn mowers, sharpening . . .	..	..	..	36-60	..	..
Malleable iron castings, large . . .	14-20	16-20	12-16	16-20	..	16
small . . .	20-30	20-30	16-24	24-36	..	20
Marble, coping . . .	..	36-46	..	..	..	..
finishing . . .	..	150-F	180-FF	..	..	..
moulding . . .	..	4	..	..	..	..
roughing . . .	..	16-16	40-50	..	..	..
sawing . . .	..	..	36-40	..	..	..
Milling cutters (machine) . . .	46-60	..	..	..	..	60
(hand) . . .	46-60	..	50-80	..	46-80	46
high speed steel . . .	..	..	..	..	46	..
sharpening . . .	..	..	60-100	..	..	..
Nickel castings . . .	20-24	20-24	20-24	..	..	..
Pearl grinding, roughing . . .	..	30-50	30-50	..	..	..
finishing . . .	..	100-150	100-150	..	..	..
Plough bodies (cast iron), surfacing . . .	..	24	16-24	..	16-24	..
(chilled iron) . . .	..	..	..	20-30	..	..
(steel), jointing . . .	20-24	..	..	20-24	..	..
(steel), surfacing . . .	16-24	..	16-24	..	..	20
points (chilled iron) . . .	..	20-30	..	..	16-24	20
Porcelain, roughing . . .	..	36-50	40-50	..	..	..
Pulleys, surfacing . . .	..	30-36	..	30-36	..	..
Radiators (cast iron), edges . . .	..	24-30	..	20	..	..
Razors, grinding and concaving . . .	46-120	..	70-100	70-100	..	..
Reamers (hand) . . .	46-60	..	..	..	46-60	46
(machine) . . .	46-60	..	50-80	..	..	60
Rods (iron or steel), ends of . . .	..	..	..	20-30	..	..
Rolls (cast iron), wet (chilled iron) . . .	24-36	24-36	24-36	..	..	..
roughing . . .	..	30-46	30-46	36-46	30	..
finishing . . .	70	70-80	60-80	60-100	90	..
Roughing generally . . .	..	..	..	20-30	16-30	16
Rubber, hard . . .	30-50	30-50	36-50	..	..	..
soft . . .	..	..	20-30	..	..	..
Sad irons, edging . . .	..	..	..	20	..	..
finishing . . .	..	80-120	120-150	..	..	..
roughing . . .	..	20-30	20-36	20-30	..	..
Safe work . . .	16-46	..	..	16-20	..	16
Saws (cold), cutting off . . .	60	..	50-80	..	..	..
gumming (heavy) . . .	36-50	..	301-365	..	..	..
(light) . . .	..	..	403	46-60	36-60	36-46
sharpening . . .	36-50	..	301-365	..	36-60	..
circular, surfacing . . .	..	..	..	36-60	..	..
Scale removal from soft steel . . .	..	..	..	20-30	..	..
Screws, finishing heads of . . .	..	..	..	36-46	..	..
Shears (cast iron), shoulders on . . .	..	..	90-100	..	..	..
Shoe lasts, bottoms and edges of . . .	..	..	..	30	..	..
Shovels, edging . . .	24	..	12-16	20-30	..	..
Springs, spiral, ends of . . .	16-20	..	..	46-60	..	..
waggon ends of . . .	20-30	..	..	30-46	..	..
Steel castings (large) . . .	12-20	..	16-16	..	..	16
(small) . . .	20-30	..	16-20	..	..	..

¹ Norton Co.'s recommendations.² Carborundum Co.'s recommendations.³ Safety Emery Wheel Co.'s recommendations.⁴ American Emery Wheel Workers' Table.⁵ Sterling Emery Wheel Manufacturers' recommendations.

TABLE LXIV.—Continued

Purpose.	Alundum. ¹	Crystolon. ¹	Carborundum. ²	Emery. ³	Emery. ⁴	Emery. ⁴
Steel castings— <i>contd.</i>						
hardened (cylindrical)	40-60 24 comb.	..	30-60	..	..	..
hardened (surfacing)	36-46	..	..	..	..	..
manganese sheet, edging	16-46	..	16	16-36	24-30	..
soft (cylindrical)	40-60 24 comb.	..	..	..	24 comb. 51	..
" (surfacing)	24-36	..	..	20-30	..	..
structural	16-21	..	..	..	16-20	..
tempered (cylindrical)	..	..	..	..	36-60	..
tempered (surfacing)	..	..	..	36-46	24-46	..
Stove castings	20-36	20-36	..	20-30	..	..
holes in	..	..	..	30-46	..	..
edging	..	..	..	30-46	36	30
moldings	..	..	..	21-36	20-30	20
Surgical instruments	..	..	16-100	..	..	..
Switches, manganese steel	14-16	..	..	..	..	..
Taps	46-60	..	..	..	46-60	46-60
Tools, high speed	..	..	..	21-36	24	..
general	20-36	..	..	..	..	..
hardened	..	..	..	80-120	..	..
lathe	20-36	..	24-36	26-46	30-46	36
machine (roughing)	..	..	..	20-30	..	..
moulding cutters	..	..	..	46-60	..	46-60
planer	20-36	..	24-36	26-46	..	36
sharpening	..	..	..	60-100	..	..
small	..	..	30-80	..	46-100	60
steel	..	..	21-36	..	..	..
" (fine)	..	..	80-120	..	..	..
woodworking	46-60	..	..	..	46	46
Tyres, steel	..	..	..	20-30	..	..
Universal grinders	..	..	..	60-80	..	..
Wagon work, wrought iron	..	..	..	20-36	..	..
Wheels, car (cast iron)	..	16-21	14-24	16-24	..	16-20
(chilled iron)	20	16-21	..	16-20	..	..
Wire, steel, ends of	36-80	..	..	70-90	..	..
Wrought iron	12-30	..	16-21	16-24	16-24	46

¹ Norton Co.'s recommendations.

² Carborundum Co.'s recommendations.

³ Safety Emery Wheel Co.'s recommendations.

⁴ American Emery Wheel Workers' Table.

⁵ Sterling Emery Wheel Manufacturers' recommendations.

In *abrasive cloths and papers* the sizes of the grains are generally used within the following limits :

Emery paper	FF to 24-mesh.
" cloth	24
Carborundum paper	20
" cloth	46
Garnet paper for woodwork	50
" cabinet work	20
Sand paper	F to 20

In considering the size of particles used for polishing, it must be remembered that, as has been shown by Beilby, there is a great difference between the action of extremely minute particles of ultra-microscopic size (such as rouge) and the much larger particles

of the finest emery or other well-known abrasive. The latter produces a smooth surface by direct abrasion, i.e. by removing the projecting particles, but the minute particles of rouge are of almost molecular fineness and so give a molecular contact simultaneously over comparatively large areas. Consequently, the particles of rouge seize those of the material to be polished, and something like a continuous sheet of molecules is set in motion. This sheet behaves precisely like a viscous liquid, filling up the hollows and furrows left by previous abrasives and covering the material with a skin of solidified liquid which is precisely comparable to a coating of varnish or enamel.

It is almost impossible to reduce any crystalline grains of sand to the almost molecular minuteness of rouge, though amorphous silica has somewhat similar properties; hence the superiority of some gelatinous forms of silica over quartz in the production of a fine polish.

Sources of Abrasive Sands.—The sources of supply of natural abrasive materials such as emery, corundum, pumice, etc., have been fully dealt with in Vol. I. Chapter III. under these various names.

Most of the artificial sands used for abrasive purposes are made where electricity is cheap, *e.g.*, where it can be generated by water power, as in Norway, South France, and in America.

Siliceous abrasive sands are obtained from various sources, *e.g.* the Leighton Buzzard sand is used for sand-blasting, and the quartz and chert gravels are used for grinding metal and plate glass. The sand at Godstone is sometimes used for scouring purposes, whilst the Reigate sand has been used in London for the decoration of glass, chiefly by sand-blasting. Lynn sand is used to a fairly large extent for making scouring soap, as are also some of the Glacial sands of Lancashire. Sand dredged from the bottom of the Mersey is sometimes used for grinding glass.

Various crushed stones are also used in soaps, *e.g.* the Appin quartzite (I. 139) found near Kentallen, Argyllshire, and the white sandstone belonging to the Carboniferous Limestone Series, near Mold, in North Wales. Ground Gornal stone (I. 154) has also been used for scouring purposes.

Selection of Abrasives.—The selection of an abrasive sand can usually be made the subject of a fairly definite specification, which should include the various properties mentioned on p. 210, particular attention being paid to the composition or nature of the grains (p. 212) and to their shape (p. 216) and size (p. 217).

When selecting an abrasive which is to be used in the form of a powder, it must be remembered that in this form an abrasive will give a coarser finish than when the same size grains are used on paper, whilst if the grains are united to form a wheel, a still finer surface, increasing with the speed of rotation, is obtained. Consequently, when a certain size of grains gives the best results when used in the form of a loose powder, a much coarser size may be used if the abrasive forms part of a grinding wheel. The other

properties of the sand remain the same, no matter whether it be used loose, mounted on cloth or paper, or compacted into a block or wheel.

Preparation of Abrasive Sands.—The preparation of sands for use as abrasives usually comprises one or more of the following methods of treatment: (1) crushing and grinding, (2) cleaning, (3) grading, and (4) drying.

Crushing and grinding.—Unless they occur naturally in the form of a sand, abrasives usually require to be crushed to the requisite fineness. The material is first reduced in a primary crusher such as a jaw-breaker (I. 347), gyratory crusher (I. 350), or other suitable machine (I. 352-359), and afterwards in a fine-grinding machine (I. 363). Although it is not economical to omit the preliminary crushing, some firms reduce the abrasive directly in edge-runner mills (I. 374) to particles about $\frac{1}{4}$ in. diameter, when the fine powders are not required. Such mills need to be specially strong and the pan constructed of manganese steel to withstand the very great wear and tear to which they are subjected. Where the abrasive is to be reduced to a very fine powder, ball mills (I. 365) or tube mills (I. 369) may be used, but at present they are not employed to any great extent in the abrasive industry.

The best and most economical method, if the material is to be reduced from large masses to the finest powder, is to use a preliminary crusher to break up the masses of abrasive to pieces about 2 in. or less in diameter. An edge-runner mill should then be used to reduce it to a coarse powder and a ball mill, tube mill, or roller mill to finish the grinding. For preparing diamond dust, a mortar and pestle are used, as the amount of material to be treated is very small.

Cleaning.—Abrasive sands may be cleaned in various ways according to the nature of the impurities present which need to be removed. Natural abrasive sands may be *washed* in a stream of water (I. 384). Where minerals are present which cannot be removed by simple washing, a *concentrating* table may sometimes be very satisfactorily employed. Corundum and emery are freed from heavy ferruginous impurities by this means.

• *Electromagnetic cleaning* (I. 428) is often useful, as in the case of corundum, emery, and other aluminous abrasives, from which much of the iron and magnetite may be removed by this treatment.

Chemical treatment is sometimes desirable to remove harmful impurities. Thus, carbide abrasives are treated with sulphuric acid to remove any iron oxide which may be present; this treatment is followed by a thorough washing and drying. Corundum crystals are sometimes heated to 600° C. in contact with fused nitre cake. This dissolves some of the impurities present and also roughens the surface of the crystals, and so renders them more effective and more easily bound together if they are to be used

in the form of blocks, wheels, discs, etc. The treated material must be thoroughly washed and dried before use.

Grading.—Abrasive sands down to 200-mesh are generally graded by means of screens (I. 441), the coarsest powders being separated by means of perforated steel or phosphor-bronze gauze, whilst the finest particles are screened through a silk lawn or very fine sieves of phosphor-bronze. Inclined and flat screens are generally employed (I. 442) for this purpose, though revolving and vibrating screens (I. 449) are also used to some extent, the screening being effected either with or without the use of water.

Sands down to 200-mesh are usually separated into twenty sizes, which are designated by the number of meshes per linear inch through which the particles will pass. The screens used have the following meshes per linear inch: 6, 8, 10, 12, 14, 16, 20, 24, 30, 36, 40, 50, 70, 80, 90, 100, 120, 150, 180, and 200. Thus, No. 6 abrasive is an abrasive consisting of particles which pass through a 6-mesh screen, but retained by an 8-mesh screen. Fine abrasive powders (smaller than 200-mesh) are graded by means of elutriation in a suitable liquid. Various methods of elutriation are described in Vol. I. p. 391, but the one most commonly used for abrasives consists in washing the finely powdered abrasive into large vats in which it is allowed to stand for varying lengths of time, and separating, it according to the time taken for it to settle. Emery which settles in 30 min. is known as "30-min." emery; that which takes 60 min. is known as "60-min." emery, and so on.

It is possible by careful working to produce very uniform abrasives up to 60-min. powders, but beyond this the grading is not so good. 100-min. powder is not so uniform as the coarser ones and contains much coarse material, as well as a certain amount of almost impalpable powder, so that 100-min. material is not much more useful, if any, than 60-min. powders.

The settling tank is generally about 3 ft. deep, but this is not always the case, so that it is impossible to say just how fine a particular consignment of 30-min., 60-min., etc., emery will be.

The fine particles separated by sedimentation are also designated by letters such as F, FF, FFF, FFFF, and by numbers such as 0, 00, 000, and 0000.

Water is generally used in grading fine powders such as emery, but for the smallest particles of carborundum, alcohol must be employed, as the fine particles of carborundum entangle air bubbles which prevent some of the coarser ones from settling, and thus cause them to contaminate the finer particles.

Diamond dust is graded by mixing it with oil and allowing it to stand for varying lengths of time, the material which has settled in each case being collected. The grades of diamond dust shown in Table LXV. are produced in this way.

[TABLE

TABLE LXV.—GRADES OF DIAMOND DUST

Time of Settlement.	Grade No.
5 minutes . . .	0
10 „ . . .	1
30 „ . . .	2
1 hour . . .	3
2 hours . . .	4
10 „ . . .	5
Remainder . . .	6

Air separators (I. 466) may be used for grading the finest powders and separating them from coarse material, though they are not used to any large extent.

Drying.—Abrasive powders are separated from water and dried by various methods. Coarse powders are allowed to settle, the water is decanted off, and the material dried artificially. Fine powders are sometimes allowed to settle and drain in large vats, but the process is slow. The usual method is to drain off as much water as possible and then to heat the residue so as to evaporate the remainder of the water. Other methods include centrifugal drying (I. 407) and vacuum filters (I. 405), but these have not been widely used.

Testing Abrasive Sands.—The principal tests to be applied to sands used for abrasive purposes are as follows:

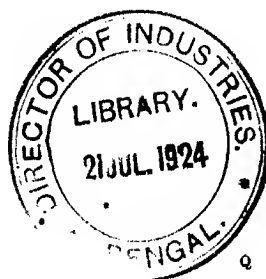
1. Chemical analysis (I. 237) to determine the composition of the abrasive and of any impurities present.

2. A microscopical examination (I. 241) to determine the composition, shape, and size of the particles and the nature of their surfaces.

3. A hardness test (I. 209).

4. A mineralogical examination (I. 256) to determine the proportion and nature of any heavy minerals, etc., is sometimes necessary.

5. A sizing and grading test (I. 246) to determine the sizes of the various particles.



CHAPTER XIV

THE USE OF SAND IN EXPLOSIVES

SOME sandy materials are used as absorbents in the manufacture of dynamite and other nitroglycerine explosives. Nitroglycerine is a liquid and a very dangerous explosive which cannot be handled safely when alone, but if it is absorbed into some porous material, the product is a solid explosive which can be handled with comparative safety.

The sands chiefly used for this purpose are : (a) sand, (b) brick-dust, and (c) kieselguhr or diatomaceous earth. Siliceous sand and brick-dust are not really satisfactory, as they have only a small capacity for absorbing and retaining the liquid explosive ; since both these materials consist of solid particles of little or no porosity, the power of absorption of sand and brick-dust is limited to the voids or interstices between the particles. Mica has also been used in Spain, but for the same reason this only holds a small percentage of nitroglycerine.

Kieselguhr, on the other hand, consists of extremely porous particles, and so is able to absorb three times its weight of nitroglycerine without becoming damp to the touch. Randanite, another form of diatomaceous earth, has also been used as an absorbent, in France.

The properties of an absorbent for explosives should be as follows :

Chemical Composition.—The sand or equivalent should be as pure as possible, but a little impurity is not harmful. It is, however, desirable to ignite the sand before use, so as to destroy as much as possible of any organic matter which may be present in it ; this treatment also increases the absorptive capacity of the material.

Porosity.—The sand or other material should be capable of absorbing three times its weight of nitroglycerine, and when the saturated material is pressed, the liquid should not be squeezed out. Kieselguhr is the only material which properly fulfils this specification ; sand and brick-dust are far inferior to it in this respect. The great porosity of kieselguhr and diatomaceous earth is due to each individual grain being itself porous and skeletal in character, as distinct from the solid grains in other materials.

Size of Particles.—The sand or other material should consist of very small particles and should leave no residue on a 30-mesh sieve, as the presence of any coarse grit may cause abrasion and prematurely explode the nitroglycerine. The grains should be rounded and as uniform as possible in size, as this will ensure a material of maximum porosity between the grains.

Dryness.—The material should not contain more than 0.5 per cent of water, as moisture fills some of the pores and so reduces the capacity for absorption. If necessary, the material should be dried before use.

Sources.—Common sand and brick-dust may be obtained in almost any locality. The occurrence of kieselguhr is described in Vol. I. p. 96.

Preparation of Kieselguhr.—The various stages in the preparation of kieselguhr for use as an absorbent are as follows :

1. Calcination to burn off any organic matter.
2. Grinding to required fineness (I. 363). For this purpose, crushing rolls are usually employed.
3. Screening to remove coarse particles (I. 441).
4. Drying by artificial heat (I. 408).

Sand, brick-dust, or other materials which may be used may not need to be calcined, but otherwise the mode of preparation is the same.

Tests.—The following tests should be applied to kieselguhr or other material to be used as an absorbent for nitroglycerine :

1. A cleanness or elutriation test (I. 252) to ensure the absence of dirt, clay, or other objectionable impurities.
2. A sizing or grading test (I. 246) to determine the sizes of the various particles.
3. A microscopical examination (I. 241) to show the shape of the particles.
4. A moisture test (I. 238) to ascertain the percentage of moisture present.
5. A porosity test (I. 261) to show the amount of explosive which can be absorbed by the material.
6. A chemical analysis (I. 237) is seldom necessary.

CHAPTER XV

MISCELLANEOUS USES OF SAND

THERE are many uses of sand in addition to those previously mentioned. In some of these the nature of the sand is of little importance, except where such properties as fineness, roundness of grains, etc., are essential. It would be difficult to compile a list of all these various uses, but some of the principal ones are given in the present chapter.

Absorbent.—Sand is sometimes used as an absorbent of acids and other corrosive liquids. The properties which it should then possess are the same as those described in Chapter XIV. Before the invention of blotting-paper, fine rounded grains of white sand were largely used for the same purpose.

Annealing.—On some occasions, where very slow cooling or annealing is essential, the hot articles may be covered thickly with sand, which then prevents the heat from escaping rapidly from them. Almost any kind of sand may be used, but it should be fairly fine and dense.

Ballast in ships often consists of sand. It need not consist of any particular quality, though a saleable sand is always preferable to one of no commercial value, as in that case the price realised may contribute to the cost of running the vessel.

Coking.—Sand is sometimes added to the coal charged into retorts or coke ovens in order that it may combine with any bases which may be present. For this purpose the sand should be very fine and as rich as possible in silica. The purity of the sand is not of great importance if sufficient free silica is present. The sand raises the melting point of readily fusible silicates in the coal, and in this way prevents excessive corrosion of the oven- or retort-walls. Its value is, however, very small in comparison with its disadvantages.

Erasers.—Sand is sometimes used to erase marks of various kinds; this use is only a form of abrasion, the use of sand for which is described in Chapter XIII.

Filler.—Sands of various kinds are extensively used as fillers or extenders. In some cases they are merely cheap diluents or adulterants, as in the well-known, yet largely imaginary, admixture

of sand with sugar ; in other cases they serve to spread a particular material, such as a paint or cement, over a larger area, and so use it to better advantage. For these purposes the sand should be white or almost colourless, and the grains should be very small ; they should readily pass through a 200-mesh sieve. The chemical composition and most of the physical properties are of minor importance, though rounded grains are usually preferred to smooth ones. Very fine grinding is usually an essential feature of the preparation of the sand for use as a filler. See also *Paints (below)*, *Soap* (p. 230), *Roads* (p. 60), etc.

The use of sand for filling up holes in the ground, in rocks, disused mine workings, etc., scarcely needs more than a bare mention.

Friction sands are used on tram ears, locomotives, etc., to enable the wheels to grip the rails. For this purpose, the sand must be very hard, so as not to break under the great load placed upon it. It should consist of angular particles of approximately uniform size, so as to give a maximum grip, and should be as dry as possible, so as to form a thin even coating when dropped on to the rails. Sand is also used to create friction between belts and pulleys and in various other ways, some of which are largely undesirable.

• **Hour-glasses**, and those used for timing the boiling of eggs, contain sand, which runs from the upper container to the lower one when the glass is inverted. For this purpose, the sand must be fine and consist of round grains which will roll over one another and not adhere to each other in the small opening connecting the two vessels. The grains should be uniform in size.

Paint Manufacture.—Sands are employed in paint manufacture in three ways : (a) as fillers, (b) in pigments, and (c) for decorative purposes. As a filler, finely ground sand or kieselguhr is often added to paints to increase their bulk. It also serves to extend the colour and use it to better advantage, as well as to modify it and so produce effects not otherwise obtainable. For use as a filler, the sand must be extremely fine, leaving no residue on a 200-mesh sieve. The finer it is the better will be the resultant paint, as the filler will remain longer in suspension. Rounded grains are preferable and render the paint easy-working.

• Sand or kieselguhr is an ingredient in mixtures used for preparing certain pigments such as ultramarine, cobalt blue, smalt, etc., as described in Chapter X.

Sands may be added to paint where a stone-like surface is required, or the sand may be sprinkled on after the paint has been applied. Sand is sometimes sprinkled over black varnish to give a rough sandy effect on a black background.

The sand used for paints should depend on the effect required ; this will determine the fineness or coarseness of the sand and also its colour. The sand should not be contaminated by any material which will be deleterious to the colour of the paint. Rounded particles are preferable to angular ones, because they will give a

greater covering power to the paint as the grains roll over each other more readily.

Rubber is sometimes adulterated with kieselguhr or amorphous silica to increase its bulk. For this purpose, high porosity, lightness, and extreme fineness are the desirable features, so that the sand does not affect the properties of the rubber. Some abrasive rubbers may have rather coarser material in them.

Sand seals in kilns, producers, etc., consist of channels filled with sand, in which a sheet or slat slides or is fixed so as to prevent any heat or gases passing out of the structure. Sand is used instead of a liquid because it so readily withstands a much higher temperature. For this purpose, the sand only requires to be refractory, fine, and preferably round-grained, so that any ruts in the sand made by the moving sheet may be immediately filled up by the sand grains rolling into it. The refractoriness must be greater than the maximum temperature of that part of the kiln, furnace, or producer, so that the sand will not sinter or fuse when the seal is in use.

Soap sometimes contains a large proportion of sand, pumice, kieselguhr, or other abrasive material, which greatly facilitates the use of soap for scouring purposes. The sands used for this purpose and their properties are described in Chapter XIII. or *Abrasive Sands*. The sand must be extremely finely ground and the grains should be sub-angular and not rounded. Coarse particles must be separated (preferably by means of an air separator), as coarse grit is extremely harmful.

Water softening has been effected by the use of glauconite sands, which occur in the Greensand (I. 116) and neighbouring formations. The only desirable feature in sands for this purpose is as high a content as possible of glauconite. In most cases, other substances are preferable for softening water.

Woodworking.—Sand is sometimes used to fill defects in the surface of wood before painting or polishing the latter. For this purpose the sand is mixed with a suitable adhesive, such as linseed oil. The sand should be of a suitable colour, depending on the nature of the wood, and extremely fine so as not to produce a rough surface. In most cases a softer material, such as whiting, is preferable.

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